Bulletin No. 237

Series { B, Descriptive Geology, 43
D, Petrography and Mineralogy, 29

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PETROGRAPHY AND GEOLOGY

OF THE

IGNEOUS ROCKS

OF THE

HIGHWOOD MOUNTAINS, MONTANA

BY

LOUIS VALENTINE PIRSSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., May 11, 1904.

Sir: I have the honor to transmit herewith a manuscript entitled "Petrography and Geology of the Igneous Rocks of the Highwood Mountains, Montana," by L. V. Pirsson, and to recommend its publication as a bulletin of the Geological Survey.

This paper is a valuable discussion of one of the interesting centers of igneous rocks in a province already celebrated through the work of the author in conjunction with Mr. W. H. Weed.

Very respectfully,

C. W. Hayes,
Geologist in Charge of Geology.

Hon. Charles D. Walcott,
Director United States Geological Survey.

PETROGRAPHY AND GEOLOGY OF THE IGNEOUS ROCKS OF THE HIGHWOOD MOUNTAINS, MONTANA.

By L. V. Pirsson.

INTRODUCTION.

In the following work will be found the results of field and laboratory studies of the igneous rocks of the Highwood Mountains of Montana. The field work was carried out by Mr. Walter H. Weed and the writer, chiefly during the latter part of the summer of 1894, though the eastern part of the area was again revisited for a few days in 1896. The north-central part of the area, around the Shonkin and Arnoux stocks, was not visited by the writer, as this part of the work was done by Mr. Weed after the writer was called from the field. As the field work in petrology was incidental to the areal mapping of the region on the base map of 4 miles to the inch for the Fort Benton folio of the United States Geological Survey, under charge of Mr. Weed, the time that could be devoted to a careful study of details was necessarily limited. Future studies of the district may therefore bring out minor features which were not seen or which are but briefly treated.

As the result of this work during recent years a number of papers dealing with features of especial interest in the area have been published by Mr. Weed and the writer, including a summary account of the geology of the district by Mr. Weed in the Fort Benton folio. A list of these papers will be found in the bibliography (p. 15). It was also our intention to prepare a complete memoir on the geology and petrography of the region, but pressure of work in other and more important directions prevented this, and finally the writer was intrusted with the task of preparing a report on the geology and petrography of the igneous rocks. Since, however, the Highwoods are a group of eroded volcanoes, rising through almost undisturbed Cretaceous strata, the main problems of geologic interest connected with them are necessarily of a petrologic character and are therefore treated in this report. In carrying out the work the writer is under great obligation to Mr. Weed, who has freely tendered not only the material collected but also his field notes, maps, and photographs, and who has made many valuabe suggestions concerning the geology. The value of the work is therefore in large measure due to him.

Thanks are also due to Dr. H. S. Washington, who kindly allowed the writer to use, in advance of publication, the results of his collected tables of analyses, which proved of service in comparing a number of the types described with those of other regions.

CHAPTER I.

GEOGRAPHY AND HISTORY.

LOCATION.

The mountain group whose igneous rocks are described in this bulletin is one of the series of detached isolated areas which lie scattered about on the great plains of central Montana. Far to the west rises the great and continuous wall of the main chain of the Rocky Mountains, while to the east for a long distance stretches the level plains country. To the traveler going westward by the Great Northern Railway, these mountain clusters, rising in the distance blue and cloud-like from the level plain like islands from the sea, are the first mountain elevations seen after crossing the great basin of the

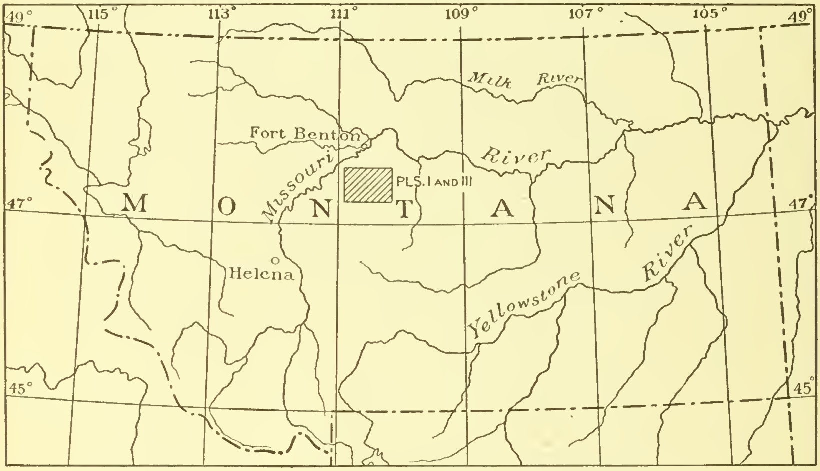
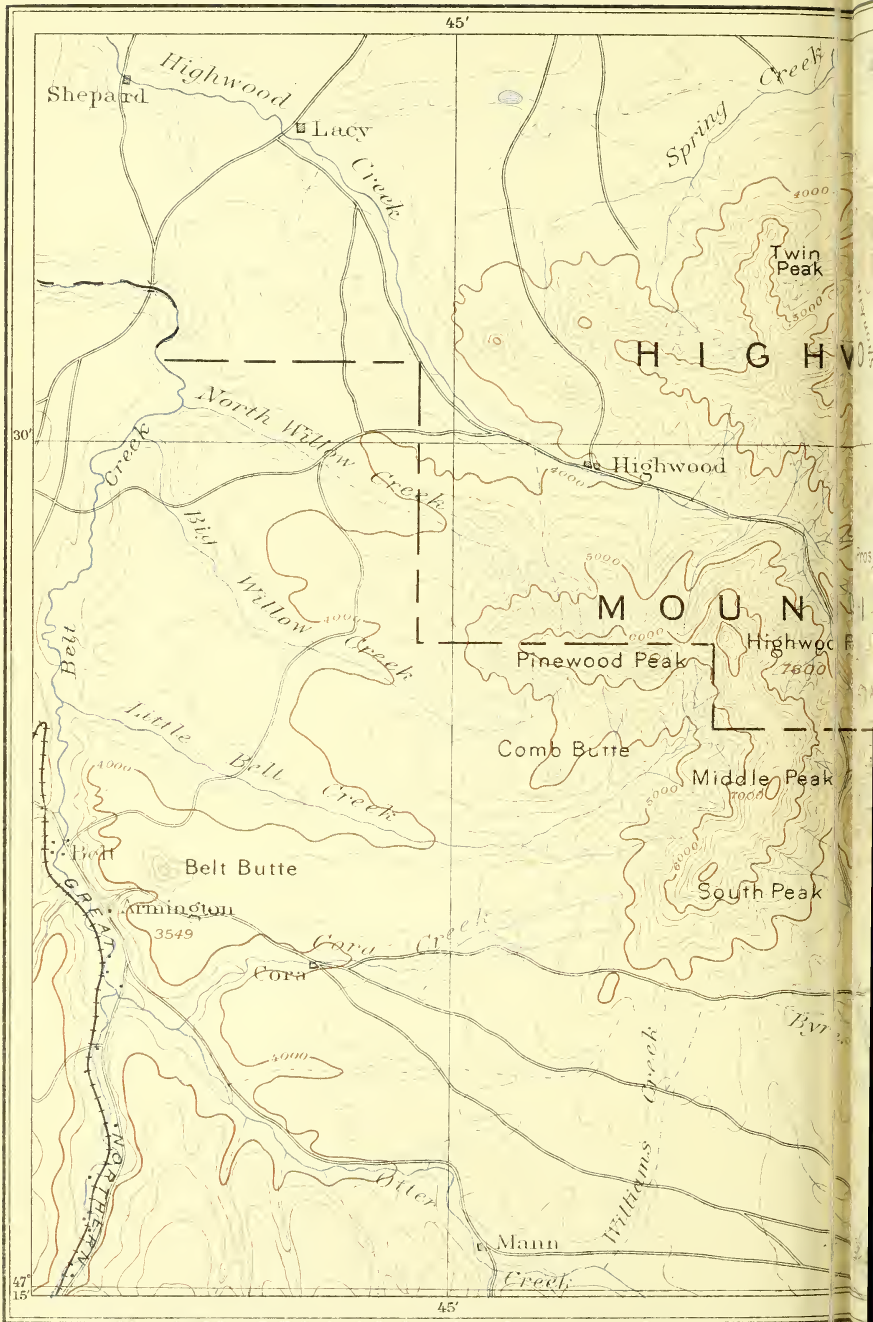


FIG. 1.—Index map showing location of Highwood Mountains.

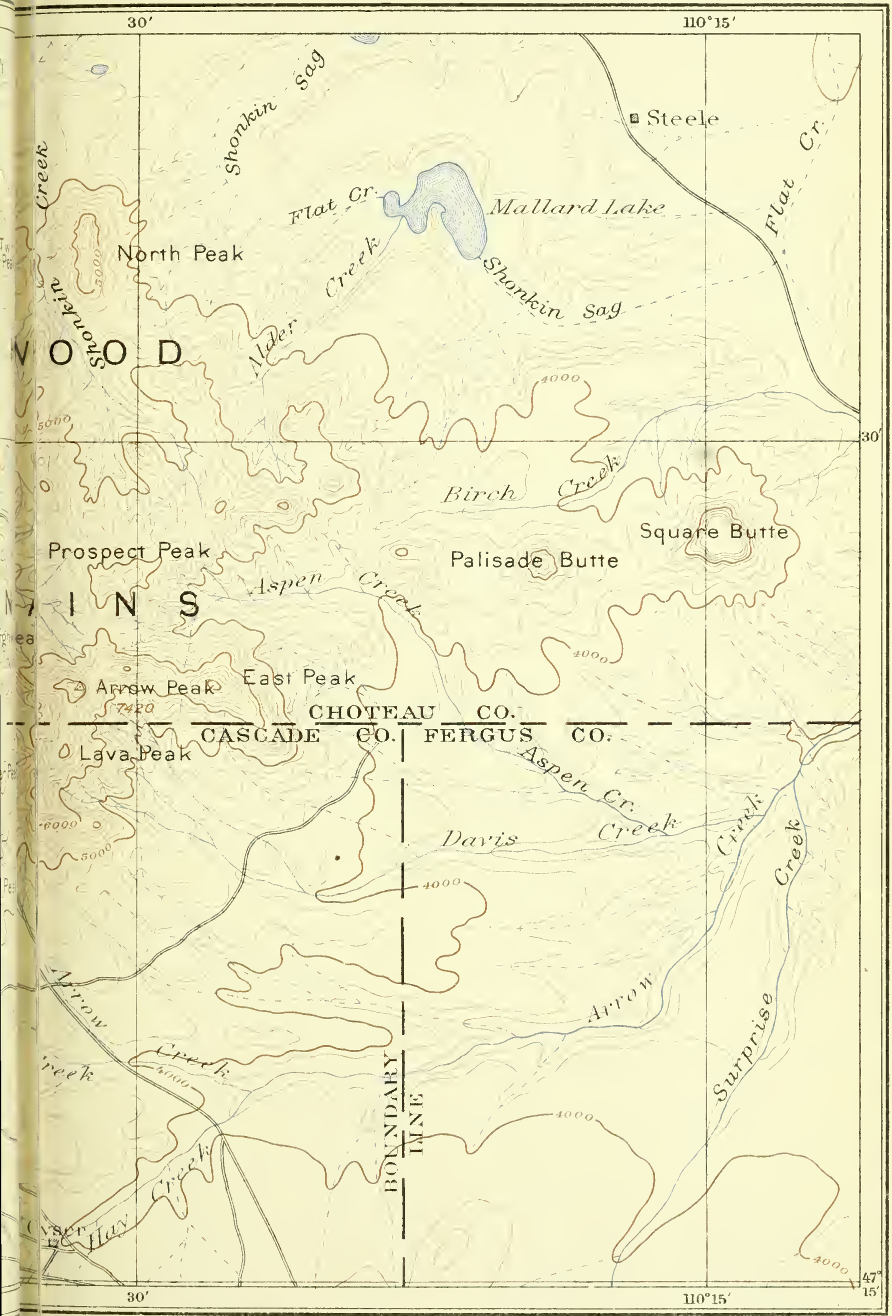
Mississippi-Missouri system. The Highwood Mountains lie within the great bend made by the Missouri River as it flows across the plain after it issues from the eastern ranges of the Rocky Mountain system. They are definitely located by the meridian of 110° 30′ west longitude and the parallel of 47° 30′ north latitude, which intersect in the center of the group. The nearest mountain ranges are the Little Belt Mountains, about 20 miles to the south, the Bearpaw Mountains, about 50 miles to the northeast, and the Judith Mountains, about 50 miles to the southeast.

The area is reached on the north and east from Fort Benton on the Great Northern Railway, about 20 miles from the foothills. The stage route from Fort Benton to Lewistown passes by the eastern side



Henry Gannett, Chief Geographer
A.H. Thompson, Geographer in charge
Triangulation by E.M. Douglas
Topography by Northern Transcontinental Survey
Surveyed in 1883-7

TOPOGRAPHIC MAP OF THE



IGHWOOD MOUNTAINS, MONTANA

JULIUS BIEN & CO. N.Y.

Scale
6 7 8 9 10 miles
10 kilometers
al 200 feet

of the area, and there are relay stations and post-offices at Steele, about 4 miles east of Mallard Lake, and at Campbells, east of Square Butte. On the south and west the region is reached from Belt and Armington, towns on the Little Belt branch of the Great Northern Railway.

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TOPOGRAPHY AND GEOGRAPHY.

The elevated tract comprised in the Highwood Mountains in its greatest extension is about 25 miles long from east to west and 16 miles wide from north to south, and has a total area of 250 to 300 square miles. The outer foothills are rather low and rounded, with few craggy or broken tops. Toward the center the country becomes more rugged and the highest elevations are sharp peaks which rise 3,000 to 4,000 feet above the plains country and 6,500 or 7,500 feet above the sea. On the south side the descent to the plain is much more abrupt

than on the north. The two highest mountains, Highwood Peak (7,600 feet) and Arrow Peak (7,420 feet), are separated by a deep pass known as Highwood Gap, which, with the valleys descending from it, divides the mountains into two portions. One of the main roads across the mountains runs through this pass. A view of the mountains, looking north from near the divide in Highwood Gap, is given in Pl. II, *A*.

On the south the streams drain into Arrow Creek, which heads in Highwood Gap; on the west they are tributary to Belt Creek. The northern portion of the area is drained by the heads of Highwood and Shonkin creeks, which flow directly into the Missouri. Within the mountain tract the streams are bright running brooks of clear cold water, generally with abundance of trout and whitefish; but as they debouche upon the plain they are apt to become sluggish and alkaline from the Cretaceous clays, and in summer are sometimes dried away to standing pools. The upper stream valleys, cut in the rather soft Cretaceous beds or volcanic breccias, are of typical V form, with rather sharp descent. The general form of the drainage is radially outward from the mountain group and of branching pattern.

The slopes, except where broken by the projecting craggy walls of protruding dikes or sheets, are rather smoothly modeled, talus heapings and screes being somewhat uncommon, and are usually carpeted with a thick growth of grass. The upper northern slopes, however, are covered by heavy forests of small pines and often by dense thickets of the lodgepole pine (*Pinus murrayana*). There is no doubt that these thick blankets of pine on the northern slopes caused the mountains to receive the name "Highwoods."

The outer foothills, and especially the openings of the valleys upon the plains, are generally utilized as ranches, and the available water is used for irrigation. The higher slopes and the semiarid stretches of plains country are given up to pasturage.

All parts of the area are very accessible, as roads run up all the valleys and in one or two places cross the higher ridges. The generally smoothly modulated mountain slopes are easily traversed on horseback.

The temperature shows the same range that generally characterizes Montana, although extremes of heat and cold are greatly moderated by the dryness and vigor of the atmosphere. As the mountains stand isolated upon the plain they are condensers of moisture, and in summer time are frequently the focus of local thunder storms that help to keep green the vegetation of the higher slopes.

HISTORY.

So far as known to the writer, the Highwood Mountains are first mentioned in the reports of the Lewis and Clark expedition,[a] though they are not given a definite name. They are mentioned several times

[a] Coues's History of Lewis and Clark Expedition, vol. 1, p. 342.

A. VIEW NORTHWARD FROM HIGHWOOD GAP, SHOWING SLOPES OF VOLCANIC DEBRIS.

B. UPPER DAVIS CREEK; MOUNTAINS OF VOLCANIC FLOWS AND BRECCIAS.

by Governor Stevens in his report,[a] and it is evident from his narrative that nearly all the mountain groups and streams of this region had then, in 1853, received the names they now bear. The Belt Mountains are called by him, however, "Girdle" Mountains, and a variant of Shonkin is Shonkee Creek, which is probably a misprint. The pine timber on the Highwoods and its probable usefulness to the surrounding region in the future is commented upon by him. Lieutenant Mullan of the Stevens expedition,[b] with a detached party, ascended Shonkin Creek and passed to the east of the Highwoods into the Judith basin. He speaks of the first spurs of the Highwoods as being a thousand feet in height.

In 1860 Lieut. John Mullins[c] passed along the same route on his way from Fort Benton to Fort Union. His first camp was in the foothills on the northeast side of the mountains, and the next day he followed the Shonkin Sag down to Arrow Creek. On the map accompanying the report the position of the mountains is roughly indicated, but their name is not given. The mountains were not visited by the Ludlow expedition in 1875,[d] but on the route map their position is shown and their name is given, together with those of the prominent peaks and the main streams.

The earliest mention of the geology of the Highwoods is by Prof. F. V. Hayden.[e] In a summary of the geologic results of Raynold's expedition, which he had accompanied, he says:

> In the Belt, Highwood Mountains, and indeed all along the eastern slope in this region we find continual evidence of the outpouring of the fluid material in the form of surface beds or in layers thrust between the fossiliferous strata. These igneous beds thin out rapidly as we recede from the point of effusion. A large number of these centers of protrusion may be seen along the slope of the mountains west of the Judith Range. The erupted material sometimes presents a vertical wall 300 feet high, then suddenly thins out and disappears.

Almost the same wording is used in his report accompanying that of Warren's explorations.[f] This statement applies very well to the laccoliths of the region. From Raynold's[g] report we know that Mullins, whom Hayden accompanied, passed down the valley of what is now called the Shonkin Sag to Arrow Creek, and thus passed the cliff wall of the Shonkin Sag laccolith. He probably had this in mind when writing the above, and also in his report on the geology of the country traversed by the expedition, which appeared about ten years later. In this he says:

> From Fort Benton we crossed the prairie country in an easterly direction not far from the foot of the mountains. We find the cretaceous beds predominate,

[a] Explorations and Surveys for a Railroad Route to the Pacific, vol. 12, pp. 123, 173, 239.
[b] Ibid., p. 123.
[c] Raynolds, W. F., Exploration of Yellowstone and Missouri Rivers in 1859-60, 1868, p. 93.
[d] Ludlow, W., Reconnaissance from Carroll, Mont., to the Yellowstone Park, 1876, p. 14.
[e] Am. Jour. Sci., 2d series, vol. 31, 1861, p. 233.
[f] On the Geology and Natural History of the Upper Missouri, 1862, p. 119.
[g] Op. cit., p. 163.

with here and there indications of eruptive rocks, and we know that the mountains that surround us on every side are very largely composed of that material. The country is covered with saline lakes, which add much to the desolateness of the scenery. We have near the Arrow Creek a bed of erupted material thrust between cretaceous rocks, which presents a vertical wall of 150 to 200 feet at one point and then suddenly ceases. These small centers of effusion of melted rock seem to cover this whole region. The most conspicuous examples of ejected material are the Square Buttes, which is a general name for numerous peaks with broad, flat upper surfaces and with a tendency to a lofty, square, columnar form. The cretaceous rocks, so far as I can see, seem to extend quite closely up to the mountain elevations, and everywhere present the lithological character of No. 2. Arrow Creek is a small stream with a narrow fringe of cottonwood, surrounded with high bluffs forming very rugged features, properly called Bad Lands. On Arrow Creek I found ammonites, cardium, baculites, inoceramus, etc. The cretaceous rocks in this region seem to belong entirely to No. 2, though Nos. 1 and 2 may be included. It is mostly a black plastic clay, with now and then a bed of sandstone. The igneous rocks in this region show very distinctly the origin of the vast quantities of saline matter which covers the ground and mingles with the waters of the streams. These rocks seem to contain large quantities of this saline material, which gathers upon their surface, giving to the igneous peaks a whitish appearance. This may account for the great quantities of it which pervade the formations in the West.

Beyond the few observations of these early explorers, the first geologic examination of the district was made by W. M. Davis and W. Lindgren, at that time attached to the Northern Transcontinental Survey, in 1883. They traversed the mountains through Highwood Gap, collected material, and the results of their reconnaissance, showing the essential geologic features of the mountains, have been published.[a] In this report Lindgren gives a brief résumé of the petrography of the igneous rocks, showing what interesting types the region affords. This sketch of the petrography of the area will be alluded to more in detail later on. Lindgren continued his petrographic studies of Highwood material, and in 1890 published a paper on the analcite-basalts,[b] which was followed in 1893 by an article on the syenite of Square Butte,[c] with included chemical analyses by the late Dr. W. H. Melville, this last paper being based on material collected by Dr. C. A. White.

In 1894 the area was explored and mapped by W. H. Weed and the writer for the purpose of studying the areal geology and mapping the Fort Benton quadrangle for the United States Geological Survey, the work being in charge of Mr. Weed.

The writer was not able to complete the field season on account of other duties, and hence a portion of the area around the head of Shonkin Creek and the Shonkin stock was not seen by him, the work being completed by Mr. Weed, and the material collected by him. In 1896 a brief visit was made by Mr. Weed and the writer to the

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[a] Tenth Census, vol. 15, p. 709.

[b] Proc. California Acad. Sci., ser. 2, vol. 3, 1890, p. 51.

[c] Am. Jour. Sci., 3d ser., vol. 45, 1893, p. 286.

laccolithic area on the eastern side of the mountains, at which time the Shonkin Sag laccolith was studied.

As results of this field work and collection of material a preliminary sketch of the geology of the mountains, accompanied by a detailed study of the petrology of Square Butte, was published by Mr. Weed and the writer in 1896,[a] and this was followed by two papers, one dealing with the description of missourite,[b] a new type of leucite rock occurring in the Shonkin stock, the other with the geology of the Shonkin Sag and Palisade Butte laccoliths.[c]

The results of the areal work and mapping have been presented in the Fort Benton folio of the Geologic Atlas of the United States, with descriptive text by Mr. Weed.

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[a] Bull. Geol. Soc. America, vol. 6, 1895, p. 389.
[b] Am. Jour. Sci., 4th ser., vol. 2, 1896, p. 315.
[c] Ibid., vol. 11, 1901, p. 1.

CHAPTER II.

GEOLOGY OF THE IGNEOUS STOCKS.

INTRODUCTORY.

Briefly stated, the general geology of the Highwood Mountains is that of a group of extinct and greatly eroded volcanoes. Beyond this the details are largely of local and in only a few particulars of general interest. On the southeast of the mountains, and scarcely separated from them, is a restricted area of intruded sheets and laccoliths. In the eroded volcanic area proper occur all the concomitants of violent extrusive volcanism. There are central cores or stocks representing the main canals to large bodies of magma below; there are great masses of piled-up breccias mingled with lava flows, which are, however, only remnants of former lofty cones; finally, there are networks or systems of dikes surrounding and dependent upon the central cores, cutting sediments and breccias alike, and generally showing a remarkable radial arrangement around the centers of eruption to which they belong.

Brief accounts of the general geology of the Highwoods have been already given by Mr. W. H. Weed and the writer,[a] and in somewhat more extended form by Mr. Weed.[b] It is intended here to describe only such salient features as are necessary to an understanding of the petrology of the area, the main purpose of this bulletin. In essential points the descriptions here given are similar to those in the works just cited, though presented in more extended form. The geologic map (Pl. III) is taken from the map given in the Fort Benton folio.

HIGHWOOD PEAK STOCK.

The highest peak in the mountains marks the location of an approximately circular body of granular igneous rock about a mile in diameter. The igneous mass is in contact in places with Cretaceous sandstones and shales which are disturbed and metamorphosed and in places with breccias which have been indurated by it. It consists of two very distinct and separate types of rock, one a syenite of Albany type (pulaskose in the new classification), the other a monzonite (shoshonose). As one is so feldspathic and devoid of dark minerals that

[a] Bull. Geol. Soc. America, vol. 6, 1894, p. 389.

[b] Description of the Fort B ton quadrangle, Geologic Atlas U. S., folio 81

LEGEND

SURFICIAL ROCKS

Pbg
Bench gravels

Pgd
Glacial drift and till

SEDIMENTARY ROCKS

Km
Montana formation
(clay-shale with sandstone interbedded and at the top)

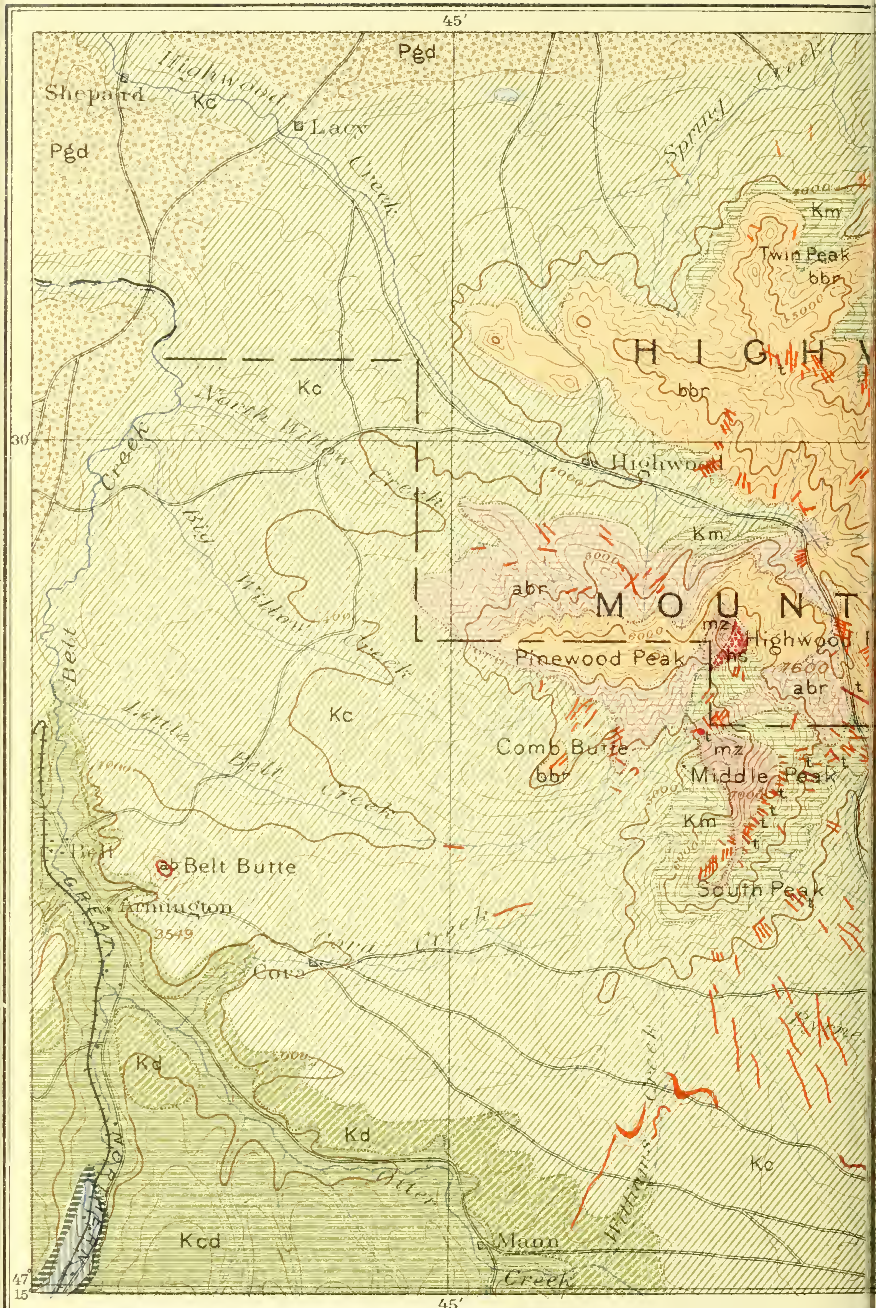
Ke
Eagle formation
(white sandstone with lignite seams and clay)

Kc ab
Colorado formation
(black shale at the base gray shale above, and sandstone interbedded; contains an ash bed, ab*)*

Kd
Dakota formation
(sandstone and interbedded clay shale)

Kcd
Cascade formation
(sandstone and shale with coal seam at the top)

Je
Ellis formation
(limestone grading upward into sandstone and pebbly sandstone at the base)



Henry Gannett, Chief Geographer
A.H.Thompson, Geographer in charge
Triangulation by E.M.Douglas
Topography by Northern Transcontinental Survey
Surveyed in 1883-7

GEOLOGIC MAP OF THE HI

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Contour in

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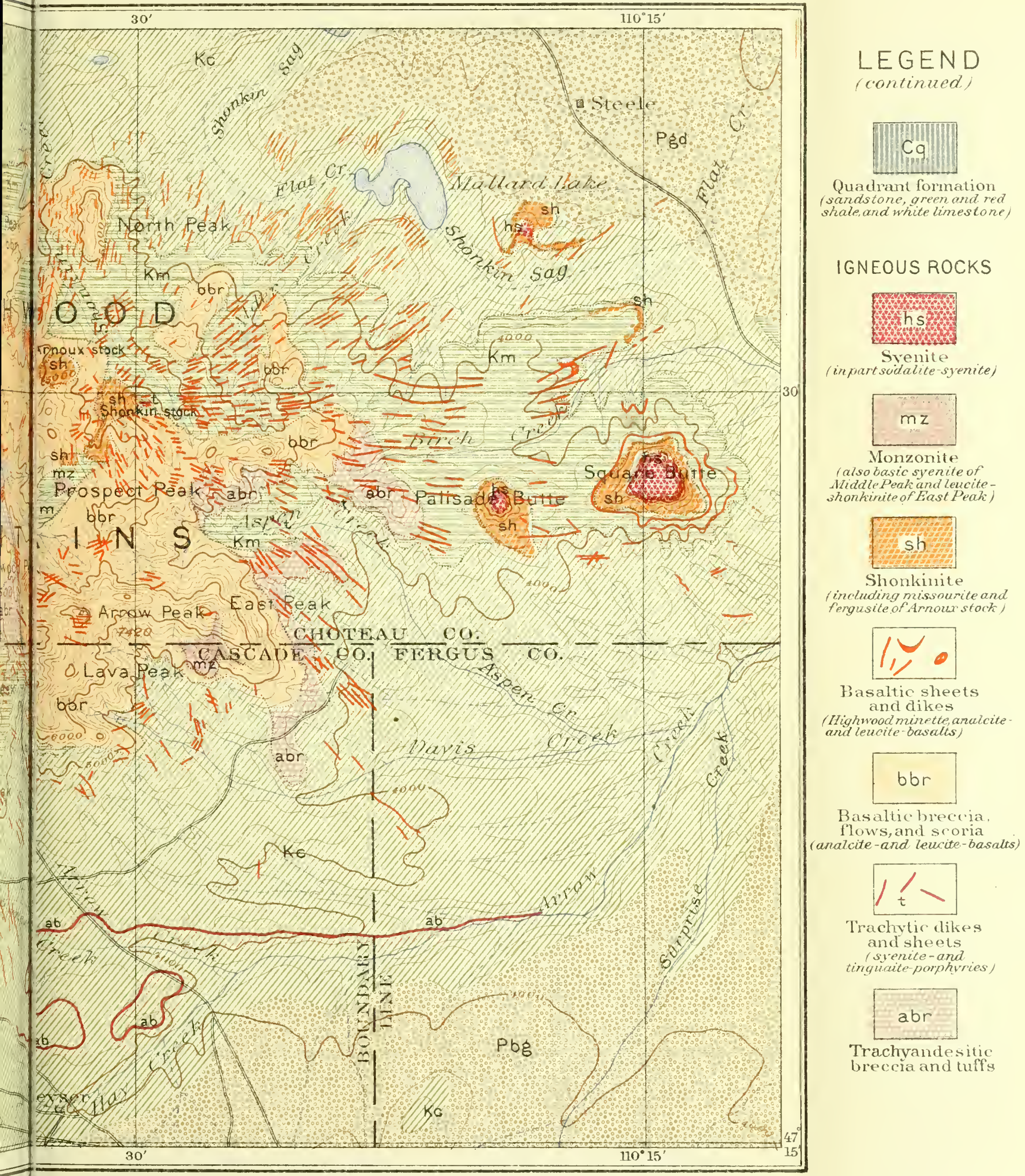


HIGHWOOD MOUNTAINS, MONTANA

Scale

6 7 8 9 10 miles

10 kilometers

Contour interval 200 feet

Geology by Walter Harvey Weed and Louis V. Pirsson
Surveyed in 1894

CO. N.Y

it appears almost white in considerable masses and the other is very dark, the contrast between them is pronounced. On the southern portion of the peak the syenite forms the exposed crags, and outcrops on the slopes and in the heads of the valleys. Masses of upturned and altered Cretaceous beds are seen lying against it, but they are not large and, so far as can be told, its intrusion was not followed by any extensive or important displacement or rupturing of the sediments. The coarsest-grained rock, of a somewhat miarolitic type, is found in the highest masses exposed, but nearly everywhere the rock is moderately coarse.

Along the divide running to Middle and South peaks are occasional outcrops of massive rock above the smooth slopes of gray indurated ash. It appears probable that they represent apophysal tongues of somewhat differentiated character, which extend in this direction perhaps as irregular dike-like masses, and, as they occur at irregular intervals, may possibly extend to and connect with the Middle Peak mass.

On the summit of Highwood Peak the light-colored rock soon gives way on the north to dark-colored monzonite. The contact between the two was not observed in place on the summit, but among the slide-rock débris of the west slope are found not infrequently pieces showing the two types in contact. In these the white syenite holds small angular chips and fragments of the monzonite, torn and displaced from a wall of the dark rock, and it is inferred that the syenite was intruded later than the monzonite.

At the north end of the peak the monzonite becomes very dense and trap like, and it is supposed that the contact is close by in this direction. The peak is sharp on all sides, and the exposures of the crest give way rapidly to a rolling talus of small fragments, which in turn is succeeded by the smoothly modeled grassy contours of the lower parts. In such places the structure is not exposed, but can only be inferred from the crest above.

Taking into consideration the rudely circular form of the mass, the grain of the rock, the small amount of displacement of the inclosing strata, the numerous radiating dikes, and the surrounding breccias and flows of lava, it appears almost certain that the core of igneous granular rock forming Highwood Peak represents the plugged canal of a former volcano. This core of igneous rock was once of much greater height and size, and the column of liquid lava rose through the conduit of sedimentary rocks into a cone of mingled ashes and breccias. The size of this cone can not now be accurately determined, but it was certainly considerable as compared with the present size of the mountain mass, as is indicated by the portion still remaining west of Highwood Peak and forming the high, narrow ridge called Pinewood Peak. This consists of dark-colored, basic breccias overlying lighter, more acidic ones, indicating variations in the character of the material erupted at different periods.

Since the cessation of igneous activity a large amount of erosion has occurred, removing the overlying breccias and flows in great part, leaving masses of them here and there and in other places cutting into the sediments, so that now the core is well exposed, and being the central and most resistant rock mass of the complex, it now forms the highest peak.

CHARACTER OF THE BORDER CONTACT OF HIGHWOOD PEAK STOCK.

On the southwest slope of Highwood Peak the character of the contact at the periphery of the mass is such that it deserves especial mention. Here outcrops of igneous rock run tongue-like down the mountain slope, with strips of inclined, much altered, sediments between them. The main rock is the syenite of the crest, mentioned above, but it contains some mica in addition to the augite. It is here cut by or is in contact with stringers and masses of a kind of "mica trap"—a dark ferromagnesian rock—at times containing much biotite in a dark-gray groundmass. This phase passes quickly, in many of these stringers and masses, into a leucite facies. The change may take place within a few inches, often in the distance of an inch. The large biotite phenocrysts disappear, the mica flakes become much smaller and more intimately mixed in the groundmass, and spots of leucite-like character appear until the rock closely resembles well-known varieties of leucite-basalt. A remarkable feature is that when the actual contacts of the light and dark rocks are examined it is found that the light incloses angular fragments of the dark, while, vice versa, the dark incloses the light. This occurs in a large number of cases, so that it is a common and persistent feature of the contact. It is also noticed, especially on somewhat weathered surfaces, that the white syenite appears somewhat streaked and eutaxitic. Observation does not reveal any change in granularity by which it may be told whether the light or the dark is the older.

Movements may have taken place in the conduit among masses of magma already differentiated, as at Square Butte, and in a highly viscous condition, or the dark rock may have been ejected through the light one and carried fragments of it upward, while the light rock held pieces of a previously solidified basic magma. The latter would seem on the face of it the more reasonable supposition, since around the peak are basaltic lavas resting on feldspathic ones. The order of succession of the igneous rocks is discussed in Chapter VII.

As one follows around the slope to the west the dark rock is seen to replace the white entirely, and the projecting masses and crags among the upturned sediments may be the roots of former effusions breaking through the side of the cone. This idea is supported by the fact that as the saddle east of Pinewood Peak is approached the rock becomes less and less granular and denser, assumes in places an

amygdaloidal structure, and finally on the saddle and on Pinewood Peak has the character of a true effusive and is even strongly pumiceous.

MIDDLE PEAK STOCK.

As previously mentioned, small intrusive masses frequently break through the level-bedded sandstones or indurated beds of ash which mostly compose the high ridge connecting Highwood Peak with Middle Peak and extending to South Peak. These are of granular rock ranging from extremely feldspathic syenites to dark basic types composed chiefly of augite and other ferromagnesian minerals. These small intrusives and also the dikes along the ridges indicate connections with deeper-seated masses below. At Middle Peak, however, is a large body or stock of granular igneous rock. The intrusion, as seen on the map, is of roughly circular outline. Its eastern edge follows the crest of the ridge along the contact with the Cretaceous sandstones, and its western boundary is on the western slope, where its presence is shown by crags outcropping among the slide-rock débris. To the south the intrusion is continued in a long tongue-like apophysis of no great breadth which runs south for 2 miles or more on the eastern side of the ridge a little below the crest. The thickness or breadth of the apophysis is, however, somewhat variable and is difficult to make out, as the lower edge is so commonly masked by débris; its outcrops are well seen on some of the spurs extending east from South Peak.

The rock composing this intrusion varies somewhat in fineness of grain and relative amount of feldspathic and ferromagnesian minerals, but in general is of medium nature. It is dark gray, moderately even granular, resembles many diorites, and in the hand specimen is extremely like the monzonite of Highwood Peak, though, as shown later in the petrographic description, there are several important points of difference. At the contact the feldspars are apt to be of pronounced tabular habit and arranged in parallel fluidal structure. In the apophysis to the south a varietal phase replaces the type of the main mass, biotite becoming a prominent ingredient. Owing to its close resemblance in the common variety to the monzonite of Highwood Peak, it has been given the same color and pattern on the map.

CONTACT PHENOMENA OF MIDDLE PEAK STOCK.

Along the crest of the Middle Peak–South Peak ridge the contact between the stock and the sedimentaries is clearly and beautifully shown. In fact, at this point the hard, tough, and resistant altered beds appear to determine the crest of the ridge, since they resist erosion better than the granular igneous rock on the one hand

and the softer unaltered shales and sandstones on the other. The igneous rock itself does not appear to be modified at the contact. The full size of grain continues directly to the contact wall, which is irregular, the igneous rock penetrating the sediments in stringers, bulbous masses, and veins for a short distance, producing a narrow mixed zone. The sediments at such places, on the contrary, are greatly altered, and where they contained lime-bearing material a greenish pyroxenic rock is produced carrying garnets and chlorite. Where they were clay slates a dark, tough, dense hornstone or adinole is produced, similar to that observed at Castle Mountain[a] and in the Crazy Mountains.[b] Changes into spotted slates, audalusite, or mica hornfels were not observed, as described by various writers at other localities.

The width of the adinole zone is probably about a quarter of a mile, not greater. The metamorphic effect dies away at South Peak, although on the crest it is still strongly marked, and while the lines of bedding are not wholly obliterated, they are twisted and gnarled, and original lime-bearing nodules are converted into hard concretionary masses, often hollow and lined with pyroxene crystals. These rocks weather purple, gray, and green on the surface. Where the metamorphism is most marked the pure sandstones have been changed into hard quartzite. The beds show great shrinkage, and in places on the ridge where they are exposed to a thickness of 15 feet they have split into prisms often several feet in diameter. They roughly resemble basaltic columns and form large blocks in the sharp-edged and chippy talus. Such shrinkage and cracking of the sediments by metamorphism about an igneous core may have an influence in permitting the intrusion of dikes into them at a later period.

ENDOMORPHIC CONTACT PHENOMENA OF MIDDLE PEAK STOCK.

The igneous rock, as previously said, holds its full size of grain, as well as could be told, to the contact, but changes somewhat in texture. The feldspars become of a more distinct tabular habit and are arranged more or less roughly parallel to one another and to the contact, so that the rock splits more easily in this direction. The effect is somewhat similar to that seen in the well-known syenite from Plauen near Dresden, and is probably the result of fluidal movements in the crystallizing magma which tended to "set" or orient the developing feldspars.

EAST PEAK STOCK.

The piled-up masses of flows and breccias that form Arrow Peak are continued to the south and east by two mountain ridges, inclosing a

[a] Weed and Pirsson, Geology of the Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896, p. 94.

[b] Wolff, J. E., Geology of the Crazy Mountains: Bull. Geol. Soc. America, vol. 3, 1892, p. 451.

basin in which are the headwater tributaries of Davis Creek. From the open country below, the view of this basin and its encircling mountain walls is very picturesque. The smoothly modeled slopes of the foothills are bare of vegetation save for the pale-brown nap of grass that covers them in summer time. In the stream bottoms is a luxuriant growth of cottonwoods and smaller trees—masses of vivid green against the brown. Above these rise the mountains, the dark-chocolate-brown of their rugged sides and crags softened here and there by forests of dark pines. The general effect, looking northward from Davis Creek at East Peak, is shown by Pl. II, *B*, from a photograph by Mr. Weed. At this point the flows and breccias composing the ridge are interrupted by a body of granular igneous rock approximately a mile in diameter and of the general shape shown on the map.

On the mountain slope this mass of igneous rock has been eroded into massive crags, pinnacles, and precipices that are noticeable at a considerable distance and from below are very striking. It ascends nearly to the top of the ridge, and on the northeast and west sides passes under the breccias which compose the ridge and which have been baked and altered by it. Its exposure slopes to the south and is terminated by a shallow, narrow valley running parallel to its face. The low ridge forming the south side of this drain also affords exposures of the massive rock in place in contact with tuffs and breccias. These latter on the slope to the south are soon replaced by the underlying Cretaceous sediments, on which it is clear they form only a shallow patch, and with which on the south side the igneous rock must be in contact at no great depth. From this exposure on the southern ridge was taken the specimen analyzed (760, p. 109).

A marked feature of this rock is the heavy massive jointing, which produces hugh angular blocks in the talus, which then weather and break down into smaller masses. The jointing causes the crags and pinnacles to have the form of great prisms or nearly rectangular masses. It gives in places a decidedly columnar aspect to the exposures. The columns are not vertical, but inclined in the same direction as the general slope of the exposed face of the mass. The breccias, beneath which the igneous rock disappears, are tilted away from it, as shown by their rough bedding lines, at angles of 10° to 20°.

All this goes to show that the stock or core in its general direction is not vertical, but dips somewhat to the north. It extended upward into previously piled-up masses of extrusive material. Whether it reached the surface and became in itself a conduit for effusions can not now be told. If effusive rocks existed at all, erosion has long since swept them away and has cut down into the stock itself and the surrounding breccias until on the southern edge they have almost disappeared.

The rock composing this stock is medium granular and pearly gray

to dark gray in color. It contains so large a proportion of augite, chiefly with other ferromagnesian minerals mingled with its feldspars and feldspathoids, as to be of rather basic type. In the specimen analyzed, taken from the exposures of the low frontal ridge mentioned above, it contains among the feldspathic components a considerable quantity of leucite, and in the prevailing terminology would classed be as a basic leucite-syenite. It is described in the petrographic portion of this work under the name "leucite-shonkinose."

SHONKIN STOCK.

This locality was not visited by the writer, and for the following notes and the specimens which illustrate the variations in the rock mass he is indebted to Mr. Weed, who studied the occurrence after the writer had left the field.

The Shonkin stock is the largest body of intrusive granular rock in the mountain area, being about $2\frac{1}{2}$ miles long and $1\frac{1}{4}$ miles in its greatest breadth. It is irregular in shape, being broader at each end than in the middle. It is in places in contact with the sedimentary strata—Cretaceous shales—and in places with volcanic ejections which lie upon them. The igneous material has been intruded into the sediments and along the contact between the sediments and the extrusive volcanic material. All this material is greatly altered by the intrusion, and through the hardened rim there depart radially outward a great number of dikes. The igneous rock, whose average type is a rather coarse, dark, granitoid-looking rock, resembling many gabbros in appearance, from place to place shows great variation in grain and a slight difference in the relation of feldspathic and ferromagnesian minerals. This is most noticeable at the south end, where a coarse agglomerate of the massive rock in blocks has a cement of finer material, the mineral composition of both rock and cement being the same as that of the main type, but showing great textural variations. This is supposed to be the actual locus of volcanic activity—the throat, in fact, of the former volcano at this place. The mass is so eroded and weathered that it seldom forms heavy outcrops, acting in this respect like many coarse-grained stocks which readily break down. Conspicuous exposures may be seen near the contact, but the rock is apt to be hidden by the talus-like material which results from the breaking down of the mass. The jointing is platy at the contact but massive elsewhere.

The rock composing this mass is made up mainly of dark ferromagnesian minerals—augite, olivine, biotite, and iron ore—but a considerable amount of a light-colored mineral is present. In some places the latter is alkali feldspar, forming shonkinite (shonkinose); in other places it is leucite, forming missourite (missourote), described on page 115. These two minerals, both white, formless and granular, look so

much alike in the hand specimen that it is almost impossible to distinguish between them, and therefore between the two rock types, by mere inspection. Moreover, there are intermediate types in which alkali feldspar and leucite are intermingled in the white portion. As these facts were unknown when the area was mapped, and as the types could not be discriminated by ordinary means in any case, it is impossible to say how much of the Shonkin stock consists of missourite and how much of shonkinite. In the specimens collected by Mr. Weed over a large portion of the stock the shonkinite greatly predominates, and it is therefore inferred to be the chief type. At some places in the Highwoods where intrusions occur near the contact, the rock mass, which consists of shonkinite, is filled with large, coarse pseudoleucites, as large as the end of one's thumb, which contain many grains of ferromagnesian minerals. This fact renders it uncertain how much of the shonkinite in this area may be original and how much may be pseudoleucitic after missourite. This uncertainty also is all the greater when one takes into account the rock forming the neighboring Arnoux stock, whose white mineral, described on page 83, consists mainly of pseudoleucite.

Occurrence of missourite.—The pure unchanged leucite type (missourite) of this stock has been already described by the writer from Mr. Weed's specimens. The rock is of importance on account of the place it fills in the prevailing systems of classification, and because until this occurrence was known, unchanged leucite had never been found in an intrusive granular igneous rock, a fact of great importance in theoretic petrography. It was supposed that the whole mass of the Shonkin stock was made up of this type, but since subsequent study has shown that this is not the case, the exact locality where typical missourite occurs will be described. For the accompanying sketch map (fig. 2) the writer is indebted to Mr. Weed. The type specimen was taken from the talus blocks at the foot of a low cliff of a reddish color above the ranches on the east side of the stream, which is the head fork of Shonkin Creek. It will be noted that the place is at the southwest foot of the mountain between the main upper mountain forks of Shonkin Creek, and is on the border of the intruded masses of the stock. The leucite of the rock at this place is a pale greenish-gray on a freshly broken rock surface, while in those places where it is replaced by feldspar the latter is white to pale pink, if one can judge from Mr. Weed's specimens.

The adinole zone of contact-metamorphosed shales is largely filled with intrusive sheets of varying thickness. These sheets are composed of types of leucite-basalt—dense dark rocks spotted with phenocrysts of augite and whitish ones of pseudoleucite, similar to those types which occur in the sheets around Square Butte and the Shonkin Sag laccoliths and whose petrographic characters are described on

page 166. The sheets and dikes are described on page 30. It should be remarked in conclusion that the edge of the stock is cut by dikes, one of which is a light-colored feldspathic porphyry (syenite-porphyry or trachiphyro-borolanose).

ARNOUX STOCK.

The Arnoux stock is a small, rudely circular mass of granular intrusive rock perhaps a mile in diameter. It is about 2 miles north-

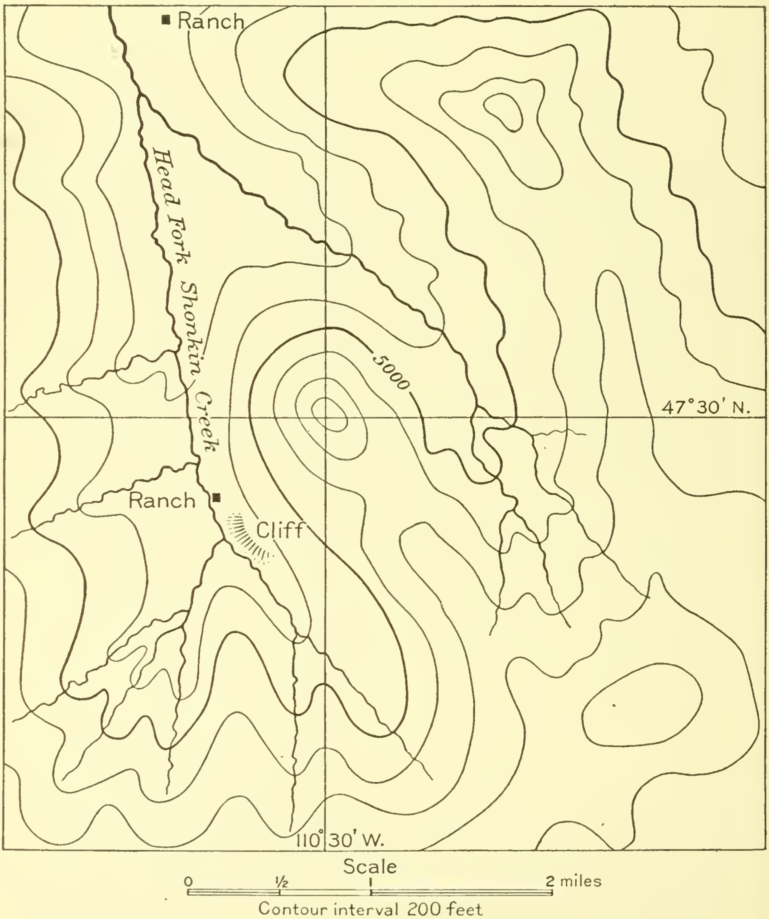


FIG. 2.—Sketch map showing locality at which missourite was found.

west of the large Shonkin stock. It is intrusive in the previously ejected basaltic breccias, which have been altered by it as at the Shonkin core. It has been cut into by a northward-draining tributary of Shonkin Creek, and although the exposures are not marked, they are good in places. While there is some variation in the rock composing it, the main type, as shown by Mr. Weed's specimens, has

a very interesting composition and consists chiefly of pseudo-leucite and a smaller quantity of augite. The rock is fully described on page 83 under the name fergusose (fergusite), as it is a new and distinct variety of igneous rock.

At some places this rock contains a larger proportion of the ferro-magnesian minerals, and at others, near the contact, the outline of the pseudoleucite may be lost, and the rock has then the appearance of the shonkinite of the other localities in the region.

This stock is entirely isolated at the surface, and as it was not visited by the writer he has no suggestions to offer concerning any possible connection with the near-by larger Shonkin stock, although this naturally presents itself as a possibility.

CHAPTER III.

GEOLOGY OF THE SHEETS, DIKES, AND EXTRUSIVE ROCKS.

INTRUSIVE SHEETS.

In the region of active volcanic outbreaks in the Highwood Mountains intruded sheets of igneous rocks do not form a prominent feature of the geologic structure. Only in the eastern laccolithic area are they important. They are not entirely wanting, however, for they have been noted in several localities—in the foothills or lowest slopes and in the open country surrounding the mountains where the trenching of the streams has revealed them, and in the altered strata surrounding the Shonkin stock. In the highest parts of the mountains they seem to be wanting among the sediments, except in one or two rather doubtful cases.

Near the Thornton ranch, on the head of the South Fork of Williams Creek, a sheet of minette of Highwood type (phyro biotitic shonkinose) is intruded into sandstones. It is about 12 feet in thickness, the upper portion being of coarser grain than the lower, has a brownish color, and weathers to a coarse sand. The lower, denser portion has a very massive parting, giving rise to large blocks which tend to weather to rounded bowlders. The sheet is full of large, well-developed mica phenocrysts, sometimes half an inch in diameter, which are more or less parallel to the general plane of the sheet and tend to cause parallel fracturing or lamination in its upper portion.

Several similar sheets were noted in the bench lands to the west of this occurrence. They commonly determine the position of the upper surface of the bench, forming, together with the baked sedimentaries, a hard layer in the soft Cretaceous strata. In one case the rock, on weathering, has developed a pronounced onion structure of concentric shells. The inner kernels may be lifted out, leaving bowls an inch or so in thickness and smooth and regular in appearance. In this instance the rock is badly weathered and the structure was evidently the result of concentric cooling, aided perhaps by a previous rolling and kneading of the viscous intrusion, which has been brought out by weathering. In other cases the sheet may have a thin platy parting at top and bottom, so that at a short distance it resembles a slaty sedimentary bed.

One of these sheets is cut by the long dikes crossing the bench lands north of Mann, on Otter Creek. In this area the beds at times show small local anticlinal dips, suggesting that they were disturbed

below by intrusion of sheets or small, flat laccoliths, which erosion has not yet exposed at the surface.

The rock forming the sheets is the minette of Highwood type (phyro biotitic shonkinose). Sheets of feldspathic porphyry so common in the Little Belt Mountains to the south are seldom found in the Highwoods. These basic sheets break down into coarse soil and rotten rock, in which the micas turn to greenish plates of chlorite. An excellent example of this may be seen on the little hill in the open country south of the mountain slopes a few miles east of the Curry ranch, which is situated where Arrow Creek debouches from Highwood Gap.

Sheets of such rock in the black shales occur above Fitch's ranch, on Little Belt Creek, near its upper forks. They were also observed by Mr. Weed in the adinole zone around the Shonkin core at the head of Shonkin Creek, where they reached 8 feet in thickness. A heavy intrusive sheet found by Mr. Weed on the creek between Alder and Birch creeks, on the eastern side of the mountains, is about 20 feet in thickness and produces a waterfall in the course of the stream; a 5-foot dike runs into it and is thought to be the feeder of the sheet. The main rock of the sheet is a shonkinite, full of rather automorphic augites, while that of the dike is a much denser basalt.

Specimens of fine compact shonkinite or basalt collected on Alder Creek above the ranches were derived from intruded sheets in the Cretaceous beds above and were mapped later by Mr. Weed.

The most striking instances of intrusive sheets in the Highwoods, however, are those found in connection with the laccoliths of Square Butte and the Shonkin Sag, and will be described in connection with these laccoliths.

DIKES.

INTRODUCTORY.

Beyond question there is no feature of geologic structure in the Highwood Mountains of greater interest than the systems of dikes. Except, perhaps, the laccoliths on the east, which are so well dissected and exposed for study, the dikes are the most striking and characteristic phenomenon of this volcanic area. They were noted by Lindgren and Davis,[a] and their systems and character were mentioned in previous works of Mr. Weed and the writer.

RADIAL DISPOSITION OF DIKES.

The most characteristic feature of the dikes is their general radial disposition around the mountain mass. This is clearly seen by a glance at the geologic map, but further study shows that the great

[a] Tenth Census of the United States, vol 15, Mining Industries, Washington, 1886; Relation of the Coal of Montana to the Older Rocks, by W. M. Davis, p. 709; Eruptive Rocks, by W. Lindgren, p. 724.

majority fall into several distinct systems; that they radiate not only in a general way about the mountains, but also about distinct loci, and that each locus is a body of granular igneous rock—the former canal of a volcano and a center of upward force and eruption. These facts are shown on the accompanying map (Pl. III), on which the actual directions of the exposed dikes are shown by the colored lines. Most of the dikes cluster about the Shonkin and Highwood peaks as centers, especially the former. Around the outer flanks of the mountains the radial arrangement of the dikes was noted as they were mapped, and the existence and character of the Shonkin stock suspected and its place located by Mr. Weed and the writer before it was visited by Mr. Weed, who was then able to prove the correctness of the supposition. It has long been known that dikes radiate about eruptive centers, especially on the dissected flanks of the volcanoes. The value of this arrangement as a means of locating eroded eruptive centers was shown by Iddings in his work on the Crandall and Haystack[a] areas of the Absaroka Range to the south.

A radial arrangement of dikes and the principles of magmatic differentiation which have been evolved in recent years may be useful instruments in determining the geologic structure in certain cases.

If all the dikes in the Highwoods could be carefully mapped on a large scale this arrangement would be much more pronounced than it appears on the map. On account of the small scale of the map, the limited time available, and, more especially, certain reasons connected with the exposures to be mentioned later, only a part of the dikes actually existing are shown.

CHARACTER OF THE DIKES.

In many cases the dikes have proved more resistant to erosion than the Cretaceous beds they have penetrated, and now protrude as rough stone walls or "reefs." This is more especially conspicuous in the outlying foothills and open bench lands, where there is no vegetation to obscure them save a nap of short yellow-brown grass. An especially noticeable locality is near the head of Byrnes Creek, north of Mann on Otter Creek, and south of the mountains. Here a dike with a north-south trend toward Highwood Peak runs across the open country for miles. It is divided into massive blocks 3 to 4 feet on a side, which have the regularity of placement often found in dikes, which gives them an appearance of artificial construction, like masonry. Although only 8 to 10 feet wide, the wall often has a height of 10 or 15 feet for some distance. The rock is an extremely dense and heavy Highwood minette (shonkinose).

Similar dikes forming heavy projecting walls are found on the bench lands south of the mountains, in the basin of the south fork of

[a] Geology of the Yellowstone National Park: Mon. U. S. Geol. Survey, vol. 32, pt. 2, 1899, pp. 224-231.

Aspen Creek, and on the grassy slopes of the divide in Highwood Gap, where they constitute the chief geologic feature. Other excellent examples are the great wall dikes east of the Shonkin Sag laccolith and near the stage road from Fort Benton to Lewistown and the great reef dike running from Palisade Butte to Square Butte. The greatest number are found on the open foothills and bench lands and upper slopes east of the Shonkin stock, where they were studied and mapped by Mr. Weed. From the top of Palisade Butte 70 are in one view. In all the cases mentioned the rocks composing these dikes are black, heavy traps of various kinds, as described later. The width of the dikes in these cases is usually 6 to 10 feet. It is rarely so great as 20 feet.

In some cases the dikes have weathered more rapidly than the sediments, and the courses of a few are shown by shallow trenches. In these instances the soil produced by weathering is often richer than that of the adjoining sediments, appears to hold moisture better, and supports a heavier, greener growth of grass or a different kind of vegetation. The course of the dikes is then marked on the open, brown hill slopes or level bench lands by greener bands. To one looking down from the height of South Peak they appear like long green pen lines on the surface of brown paper, and their radial trend is clearly seen.

These dikes are usually composed of mica traps or Highwood minettes, which are less resistant to weathering than the other varieties of the rocks found in dike form. They have produced a greater or lesser degree of metamorphism, depending on their size and number. In some cases, as in a weathered dike near the Thornton ranch on Williams Creek, the sandstones have been altered in narrow zones to quartzite, which resists erosion so that it gives a line of two parallel outcrops on either side to mark the course of the weathered dike. The same phenomenon was seen also in the dikes cutting outward through the adinole zone surrounding the Middle Peak stock, where trenches or gaps in the metamorphosed rocks mark the site of the weathered dikes.

On the upper mountain slopes there are undoubtedly great numbers of dikes which could not be mapped with certainty. Their occurrence is marked only by small rock heaps and outcrops here and there. Since the exposures of the dense rocks of the extrusive flows are so nearly like those of the dike rocks that the difference between them can be told only by careful field study and comparison of hand specimens, the accurate plotting of a network of these dikes would have taken an amount of time which would not have been warranted by the results to be attained. This refers especially to the dikes of analcite-basalt (monchiquose) occurring on the slopes covered by breccias and flows of similar rock. Even in many cases where the

dikes occur among sedimentary rocks they are often mingled with small patches and remnants of flows.

It is certain, however, that the greater part of those occurrences, which are clear and undoubted, have been mapped, and they are so numerous that the addition of even a considerable number could add nothing more to what is already known concerning their character and geologic significance.

ROCKS COMPOSING THE DIKES.

For field purposes and mapping the dikes may be considered as composed of rocks of two main groups—light-colored feldspathic rocks, feldspar porphyries (salic type), and dark-colored basaltic ones, "traps" or basalt porphyries (femic types). Under each of these groups there are several distinct varieties, whose petrographic characters are given in detail in a later chapter, but which are here briefly noticed as an aid to their recognition in the field and to an understanding of their geologic relations.

LIGHT-COLORED FELDSPATHIC (SALIC) DIKES.

As in the intrusive sheets, the light-colored feldspathic dikes are few in number, not of great size, and, except from the petrologic point of view, of relatively small importance. Near the Curry ranch, where Arrow Creek debouches from the mountains, and in the basin of Aspen Creek they are composed of pale-brown rocks of trachytic character with hornblende phenocrysts. They occur also on the edge of the Shonkin stock on the main divide between Highwood and Shonkin creeks, where the north ridge of Twin Peaks begins, on the point above the Arnoux stock, on the slopes leading up from Highwood Gap to the Highwooden-South peaks ridge, and at the edge of the Middle Peak stock. These are light-gray or brown porphyries with embedded phenocrysts of feldspar, usually large, flat, tabular in shape, and with small black augite prisms. They are syenite-porphyries, largely composed of alkali feldspars. The dikes vary from 6 to 10 feet in width.

The most important feldspathic dike is the great wall dike in the valley of upper Highwood Creek, about a mile below the divide. This dike is gray, and although somewhat variable, averages about 12 feet in width. It trends toward Highwood Peak. It is massive but somewhat plate-like in structure, and has a sort of contact-like crust composed of very short, small prisms, under which the rock is somewhat crumbly. It contains numerous inclusions of dark-colored rock an inch or so in diameter, brought from below, and cuts dark basaltic breccias which are considerably indurated. At a distance it appears as a great light-colored wall running down the eastern slope to the stream, and is a very noticeable object. The rock is a light gray-

green with numerous small white feldspar phenocrysts. It is a peculiar tinguaite-porphyry (highwoodose).

DARK BASALTIC (FEMIC) DIKES.

For field purposes the dark basaltic dikes may be divided into three classes according to the character of the prominent phenocrysts. In each case the base or groundmass is more or less dense and ranges in color from dark stone gray to black. The first class contains prominent phenocrysts of biotite up to half an inch in diameter and is composed of mica traps or minettes of Highwood type (phyro biotitic shonkinose). The second class has prominent phenocrysts of rather large, well-formed black augites and is composed of augitophyres or augite-basalt-porphyry. The third class contains prominent phenocrysts, showing round, octagonal, or hexagonal cross sections of a white mineral which may be altered leucite, but in some cases is analcite, which is held to be often of primary origin.[a] This type may be termed, in accordance with Lindgren's suggestion, analcite-basalt. It is monchiquose.

There are few feldspathic dikes, as previously stated, and their occurrences have been given. In this section what is said of the dikes in general refers to the basaltic dikes, which are found in such numbers that it would be useless to try to give specific details of particular occurrences. In so far as individual occurrences present matters of petrologic interest these are treated in the petrographic portion of this work.

RELATIVE AGE OF THE DIKES.

There have undoubtedly been several periods of dike intrusion, and the different centers have had their own periods of formation. This renders the relative age of the dikes more or less doubtful, but in general it may be said that the feldspathic dikes cut basic breccias; that in one instance on the west side of Highwood Gap an acidic dike is cut by a basic one, and that the basic dikes cut flows and breccias of all periods and also one another, as at Highwood Gap, as shown in the accompanying rough sketch map (fig. 3). Another excellent example is seen in the bluff on the east side of Highwood Creek below the mouth of the branch creek which drains the north slopes of Arrow Peak. The dikes here cut basic (femic) breccias and one another.

Other examples of the intersecting basic (femic) dikes are found in many places, as on the southern slopes of South Peak, where three intersect at one point and form a star. It is evident that the dikes not only occur, in the main, radially disposed around the centers of eruption, as previously described, but that locally also they may

[a] Lindgren, W., Eruptive rocks from Montana: Proc. California Acad. Sci., ser. 2, vol. 3, 1890. Pirsson, L. V., Monchiquites or analcite group of igneous rocks: Jour. Geol., vol. 4, 1896, p. 679.

trend in different directions and intersect in a variety of ways. Further conclusions regarding their origin and relations are deferred until the general history of the district is discussed.

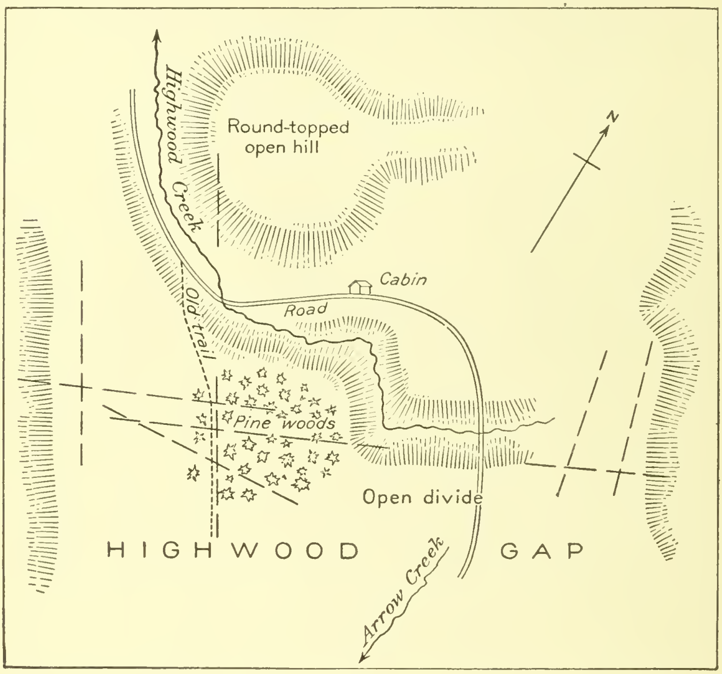


FIG. 3.—Sketch map of dikes at Highwood Gap.

EXTRUSIVE FLOWS AND BRECCIAS.

AREAL DISTRIBUTION.

In a very rough way the lower limit of a major part of the piled-up extrusive material is defined by the 5,000-foot contour around the mountains. Above this, with the exception of Highwood Peak, all of the highest summits and ridges of the group are composed of flows and breccias. The ridges, such as Pinewood Peak on the west and the great main mountain mass running northward through Lava and Arrow peaks and terminated at its northern end by Twin Peaks and North Peak, are almost entirely made up of these ejections. In some places, however, they reach down to 4,000 feet, as at the debouchment of Highwood Creek on the north side and in the valley of Davis Creek on the southeast. The sedimentary strata are found, however, also in the higher mountains, as in South Peak. These facts are of importance because they show that the eruptions have taken place over a country of irregular relief and that a great amount of erosive dissection has taken place.

FELDSPATHIC EXTRUSIVES OF THE FIRST PERIOD.

Volcanic activity began by the extrusion of heavy flows and explosive breccias of feldspathic type. These flows are petrographically between trachytes and andesites; in fact, they are trachyandesites and are described on page 160, under the name of adamellose. They occur not only in the flows as firm, dense rocks of felsitic character, but also as explosion breccias made up of angular lapilli with cement of finer material, and as tuffs and compacted volcanic ash. The greater part of this feldspathic material is found around Highwood Peak. A particularly prominent flow of it occurs on the north side, its lower part forming a marked bench. Highwood Creek just before it debouches out into the wider valley, cut in the soft Cretaceous beds, cuts through the lower end of this flow and forms a small canyon, through part of which the road passes. Other excellent exposures of these heavy flows are found on the north side of Pinewood Peak, especially on the slope leading down into the valley of North Willow Creek, where was collected the material which has served for the analysis of this type. Feldspathic flows and breccias occur also on the south side of Highwood Peak, in the basin at the head of Little Belt Creek. These rocks are light gray to brown in color, dense and felsitic in appearance, with small phenocrysts of mica or hornblende; sometimes by oxidation of the iron-bearing components they are of a deep mahogany red. The breccias are in part explosion breccias and in part, as shown by their structure, flow breccias. The finer materials produced by explosion—the tuffs—are found in the higher ridges; for example, on the ridge between Middle and Highwood peaks and on the ridge around the heads of Davis and Aspen creeks.

The natural deduction from the distribution of the trachyandesite (adamellose) lavas and breccias is that the center from which they were ejected was at Highwood Peak. The arrangement and dip of the flows and heaviest material immediately around Highwood Peak and of the finer and thinner at a distance point clearly to this conclusion.

Succeeding this period of eruptive activity came one of quiescence and erosion, during which the core that had undoubtedly been formed was largely cut away. This is shown by the fact that the succeeding basaltic ejections fell upon a country of irregular relief, spotted here and there with patches or erosion remnants of the trachyandesitic lavas and breccias. For instance, at the north foot of Highwood Peak, on the north side of Highwood Creek, the basaltic extrusives rest directly upon the Cretaceous beds, while a short distance to the south, across the creek, are heavy flows of the trachyandesitic lavas. The latter and the breccias and tuffs could not have

extended so far in other directions and not have covered the surface so near the center of activity. If the basaltic outbreaks had immediately succeeded the earlier feldspathic ones the feldspathic rocks should be found in this locality under the basaltic flows. The feldspathic rocks are absent, however, and consequently they must have been removed by erosion before the outbreaks of basaltic material took place. The same is true in other localities.

BASALTIC EXTRUSIVES OF THE SECOND PERIOD.

The second and last period of eruptive activity gave rise to material very different in character from that ejected in the preceding period. While there is a great difference between the types of this period, due partly to mineral composition and partly to texture, they have common features which sharply distinguish them from the feldspathic lavas and breccias of the first period. They are dark, heavy rocks, rich in ferromagnesian components, in augite and olivine especially, and sometimes in biotite. They belong distinctly to the basaltic group of rocks. They vary somewhat in feldspathic components, but none possess plagioclase feldspars and none are of the type of common basalt. Commonly, when they are compact rocks, there are embedded in them more or less rounded white phenocrysts, which often have more or less distinct octagonal or hexagonal outlines. In such cases they appear like the dike and sheet rocks previously mentioned, and indeed in many cases it would be impossible to distinguish the two rocks. They have also a very striking resemblance to the leucite rocks from Italy and from Lake Laach, in the Eifel district in Germany. In some cases the white component is a very fresh analcite, and these rocks are analcite-basalts, like those in the dikes. But in many other cases the white portion is composed of variable white minerals of feldspathic nature, and the rock may then be pseudoleucite-basalt. A very careful search was made for unaltered leucite in these rocks, but with the exception of one or two doubtful cases it could not be found. It seems most probable from the shape of the crystals and their general relationship to these magmas, rich in potash, that they were originally leucite, but further consideration of this question is deferred until the petrography of the basaltic lavas is taken up.

Like the intrusive rocks, the extrusives of this period generally carry numerous phenocrysts of well-formed black augites and olivine, the latter often altered to a red pseudomorphous mineral.

The breccias and tuffs of this group are dark, chocolate colored, or brown rocks running into distinct dark-purple shades in the finer tuffs. They carry fragments of basaltic rocks and are generally greatly altered and the iron-bearing components oxidized. The fragments are sometimes green, sometimes purple, and mingled with them are pieces of black shale occasionally hardened to slaty forms. In

some cases the fragments are angular, true lapilli forms; in others they are rounded, producing volcanic conglomerate. In the localities visited there was no evidence that they are water-laid.

Slaggy scoriaceous forms were found in the lavas, especially on the higher crests, as at Lava, Arrow, and Pinewood peaks. On the Lava-Arrow peaks ridge great quantities of very vesicular lava and of rounded "bread-crust" bombs were observed. Amygdaloidal forms are also common, the amygdules reaching half an inch in diameter in some occurrences. The amygdules are usually compact, with fibrous structure, consisting of various zeolites, natrolite, stilbite, etc. Sometimes, as on Pinewood Peak, the vesicular rock is full of the pseudoleucite mentioned above, and the vesicles are filled with small amygdules of about the size of shot. In such cases it is not easy to distinguish them; the rock then appears crowded with white minerals.

Distribution of basaltic extrusives.—As may be seen by reference to the geologic map (Pl. III), most of the higher peaks and ridges are made up of basaltic extrusives. Highwood Peak and the ridge running south to South Peak are practically the only exceptions to this rule. In Arrow Peak the basaltic extrusions reach their highest elevation. They form two large areas, one on the east, the other on the west of Highwood Peak, and at these places rest on trachytic (feldspathic) extrusives of the former period. They form the great central area of the mountain group, resting in part on the earlier lavas and breccias and in part on Cretaceous strata. They have been greatly eroded and are also found to the north in isolated patches of considerable size. A view of the mountain masses at the head of Davis Creek, composed of these volcanic ejections, is shown on Pl. II, *B*, which is reproduced from a photograph by Mr. Weed.

SOURCES OF THE EXTRUSIVE ROCKS.

In considering the possible sources of the various flows, breccias, and tuffs of the two periods, there are certain general facts which must not be lost sight of. In a volcanic area which has suffered little or no erosion the cones give as a general rule all the testimony that is needed in this direction. In the Highwoods, however, great erosion has taken place and the cones have been so much cut into and carried away that the remnants afford only partial evidence for their reconstruction, and additional data must be sought in other directions.

When a column of molten magma rises through its conduit to the upper portions of the earth's crust it gives rise to volcanic action. After the volcano has become extinct and erosion has progressed far enough there will be uncovered a stock of massive rock—the solidified and crystallized magma column of the conduit—which is generally surrounded by a complex of radial dikes and intruded sheets. This complex cuts into, or at a greater distance is surrounded by, still une-

roded masses of flows, breccias, and tuffs. Such phenomena have been described by Iddings at Electric Peak[a] and on Crandall Creek[b] in the Absaroka Range and by Mr. Weed and the writer at Castle Mountain, Montana.[c] Examples in other regions are also well known.

In the Highwoods there has been apparently a number of such centers of eruption, and it is difficult to determine what share each may have had in this work. As previously mentioned, the weight of evidence tends to show that the feldspathic lavas were erupted at Highwood Peak, as at this place the stock of granular rock most nearly agrees in chemical and mineralogic characters with the lavas, as may be seen by reference to the petrographic descriptions (pp. 60, 160, 191). The correspondence is not exact, of course, but an absolute chemical correspondence between a stock rock and the related extrusives is scarcely to be expected, although it may occur. Considerable divergences are noted between successive outflows of the same period, and may be caused by progressive processes of differentiation in the liquid mass below. The discussion of this subject is postponed to a later chapter. Both field evidence and petrographic relations indicate that the Highwood stock was the source of the feldspathic extrusives.

The basaltic extrusives probably were erupted from several centers. The chemical correspondence is here very close indeed if the rocks composing the Shonkin, East, and Arnoux cores are compared with the basalt selected for analysis. It seems almost certain that a large part of the basaltic extrusives of the central and northern part of the area have had their origin at the Shonkin stock center. The arrangement and bedding of the stock and the character of its south portion, which consists, according to Mr. Weed, of a tumultuous agglomerate of coarse-grained blocks in a finer-grained cement, are strongly confirmative of this. The evidence in regard to the other stocks is not so clear, and they may or may not have been centers of eruptive activity.

The basaltic flows and masses around Highwood Peak point to a renewal of activity at this center after the period of feldspathic lavas, since it seems difficult to refer those of Pinewood Peak, for example, to the distant stocks of the central area. The flows might be the surface outpourings of later dikes, but the character of much of the material indicates explosive action. If they are referred to this center there were, first, outbreaks of feldspathic lava, followed by eruptions of basaltic lavas, and the intrusion of the monzonite stock was succeeded by the intrusion of syenite. The chemical characters of these magmas and their bearing on the petrology of this center are discussed in Chapter VII, p. 190.

[a] Eruptive rocks of Electric Peak and Sepulchre Mountain: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1892, p. 569.

[b] Geology of the Yellowstone National Park: Mon. U. S. Geol. Survey, vol. 32, pt. 2, p. 215.

[c] Geology of the Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896, p. 56.

One point in regard to the origin of the basaltic eruptives remains to be noticed. On Arrow Peak heavy flows of basalt dip downward along its sides in several directions. This and the general character of the peak and its material suggest that the peak may not be a mere remnant of a once lofty cone, whose center of activity was at some distance, but may itself have been a center of activity. Otherwise these flows, whose character and attitude are unmistakable, would have to be attributed to outbreaks of dikes on the sides of an erosion remnant—a not altogether probable supposition. If Arrow Peak represents a center of activity, it is probable that there is, in some part of its base, a mass of granular rock, which is covered by flows and breccias and which erosion will one day bring to light.

CHAPTER IV.

GEOLOGY OF THE LACCOLITHS.

INTRODUCTORY.

The laccoliths of the Highwoods have been described by Mr. Weed and the writer in two previous papers, mentioned in the accompanying bibliography, on the Shonkin Sag and the Square Butte laccoliths. It has seemed best, however, to repeat in abstract the essential portion of these descriptions, partly to make this paper complete and partly because the study of the Shonkin Sag laccolith, made after the paper on Square Butte had appeared, has furnished a key to the interpretation of the structure of this latter laccolith, which the facts obtainable at Square Butte itself do not entirely afford. This has caused a modification of ideas regarding it in several respects, though it has furnished a remarkable confirmation of the views previously expressed. Moreover, while the majority of petrographers have accepted the conclusions drawn in these former papers, in their bearing on theoretic petrology, some have advanced views of their own which appear to the writer to be founded on misconceptions of the facts. It is desired to discuss these and to advance some new conclusions which further study has brought out. To render the discussion more intelligible and convenient a rather full abstract of the descriptive parts of the former papers is embodied in this chapter.

In this eastern extension of the Highwood Mountains the four principal masses of igneous rock are of intrusive laccolithic nature. In addition there are a number of dikes and intrusive sheets. There is no evidence that the forces which elsewhere in the mountains found outer vents and gave rise to extrusive material did so here; the facts all point to the opposite conclusion.

The sedimentary beds into which these rock were intruded are arenaceous shales or fissile sandstones horizontally disposed, except where the intrusions have disturbed them. They are of yielding nature and admirably suited for the intrusion of sheets and laccoliths.

As may be seen by reference to the map (Pl. III), they are cut by two drainage valleys which meet each other at a nearly right angle, that of Arrow River and that of the Shonkin Sag, in whose flat floor a feeble stream, Flat Creek, meanders. The sag is an abandoned channel of Missouri River and is easily traced on the map by the contours, the course of Flat Creek, and the scattered alkaline lakes which now

occupy it. The dissection of the land between these two drainages has exposed the laccoliths and sheets.

There are four laccoliths in this area, the major and the minor in the Shonkin Sag, Square Butte, and Palisade Butte.

MINOR LACCOLITH OF THE SHONKIN SAG.

About 2 miles due north of Square Butte, as may be seen by reference to the geologic map (Pl. III), is a mass of igneous rock intruded into the sediments. It is shown as a semicircular area of shonkinite exposed in the west wall of the sag. From the valley below, it appears as a dark cliff, perhaps 100 feet in height and a few hundred yards long. It has a columnar structure, and from the foot of the cliff a talus slopes down to the valley. It is clearly intrusive in the sandstones, and although not a symmetrical laccolith it is evidently of laccolithic nature. The rock composing it is similar to the shonkinite (shonkinose) of Square Butte. While not of great importance it has a certain interest and value, as it is another example of laccolithic intrusion, and by its confirmative testimony helps to explain the nature of the other masses, such as Square Butte and Palisade Butte, where the evidence concerning the character of the intrusion is not so clearly shown.

MAJOR LACCOLITH OF THE SHONKIN SAG.

The Shonkin Sag turns west at the small laccolith just mentioned, and about 3 miles from it in the north wall of the valley is the section of the main laccolith described by Mr. Weed and the writer. From the opposite side of the valley an excellent view of it is obtained, and it is seen as a columnar cliff about a mile long, with an even and regular face, interrupted about the center by a deep canyon-like gulch which cuts through the whole cliff. The columnar structure is pronounced, the polygonal columns having a diameter of 2 feet or more and an estimated height of over 100 feet, which is also the thickness of the laccolith along the cliff front. All along the front are seen the horizontal light-brown Cretaceous sandstones which form the floor upon which the laccolith lies. The regular, even level of this floor is very noticeable. Extending from the foot of the cliff to the valley is a great talus which is cut at intervals by rain-washed ravines. The detrital material reaches nearly or quite to the foot of the columns, and the sandstones beneath the laccolith are in places nearly concealed, but in the intervening ravines a considerable thickness of them is seen. On top of the laccolith are the horizontal, unbroken Cretaceous sandstones into which it is intruded. Their thickness is variable, as from each end of the cliff wall it gradually diminishes; about the middle, where the laccolith is cut by the intersecting gulch, the sandstones disappear and leave, especially on the eastern side, a

portion of the top of the laccolith bared. On the opposite side of the gulch, however, a considerable thickness of them rests on top of the columns of igneous rock.

Ends of the laccolith wall.—From what has been said above, it is clear that this cliff wall is the cross section of a flat mass intruded into and lying between the beds of sandstone, its laccolithic character being seen only at the outer borders.

The main body of the laccolith at the eastern end thins out until it becomes only an intrusive sheet not more than 10 feet in thickness, which on the same horizon extends a great distance into the sandstones. In addition to this main lower fringing sheet there are two

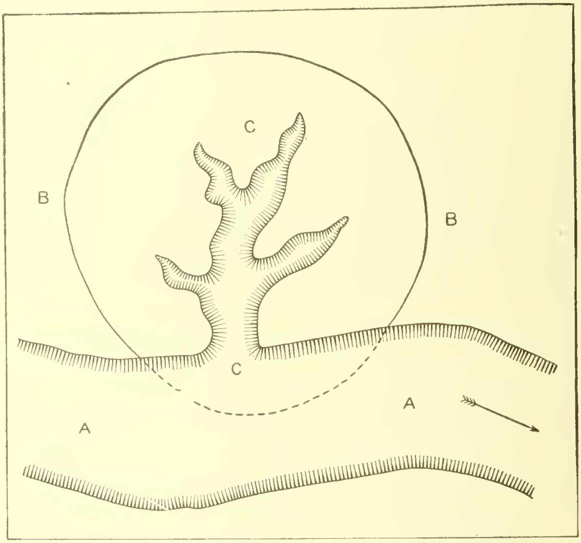


FIG. 4.—Plan of Shonkin Sag laccolith. A, former course of Missouri River; B, laccolith; C, gulch.

or three lesser ones, which do not extend far and quickly die away in the sedimentary beds.

At the western end the relations are less clear. The valley wall has been broken down and eroded somewhat, so that there is not the same vertical cut, but the exposures are sufficient to show that the structure is less typical, the beds having been affected to some extent by rupturing. The laccolith, however, frays out in thin, fringing sheets, and the basalt sheet, to which it thins down, has the same thickness and character as on the other side, and may be traced, always at the same level horizon, among the sandstones several miles up the valley. The persistency of the thin sheet of which the laccolith is a greatly thickened portion is remarkable.

The laccolith rock.—The rock composing the outer fringing sheets is dark colored, has a dense texture, and is dotted with crystals of a black augite and round white spots of an altered leucite. It may be

called a leucite-basalt. The lower 12 to 15 feet of the great columns of the main body of the laccolith are also composed of this rock, which then passes into a fully granular rock of granitic texture, consisting of augite, olivine, biotite, and orthoclase, like the shonkinite of Square Butte. At the top the columns again pass into the porphyritic leucite-basalt.

Interior of the laccolith.—It has been mentioned that the central portion of the laccolith wall is broken by a stream gorge which has cut through the laccolith into the underlying sandstones. The stream gradually rises above the sandstone until it flows over the igneous rock, and at the same time it is joined by tributary gulches, so that the whole interior of the laccolith is thoroughly dissected and laid bare.

Ascending the gulch, one soon comes to the contact of the igneous rock and the underlying sandstones. The fissile, platy sandstones at the contact are changed to a dense, flinty, blue rock, which generally has a thickness of a few inches and never more than about a foot. The igneous rock at the contact is dense and dark and is filled with augite and altered leucite phenocrysts; it is similar to the rock in the outer columns described above. It maintains this character for about 15 feet and then passes into an evenly granular, coarse-grained shonkinite. This has a columnar parting, which, as one approaches the center, is less evident than in the outer cliff wall. The drainages now lose their canyon-like character and widen out into V forms with broader spurs between them, often showing wide expanses of naked rock.

The shonkinite has a thickness of about 75 feet and is succeeded by a rock of different character. There does not appear to be any contact between the two, but the shonkinite in a little distance passes into the new type. This is a much lighter colored rock of a coarser grain. It is composed of large augites, many of them 1 to 2 inches long, often radiating from a common center in such a manner as to form stars, and of equally long but slender foils of biotite, with the interstices filled with white feldspars or feldspathic material. This rock was always found in a weathered and crumbled condition. This layer or zone is about 15 feet thick and passes above into a white syenite of medium grain, specked with augite crystals. This has a rather thin, horizontal, platy parting, by which it splits and weathers into piles of plates. On a clear day the decided contrast makes the syenite seem white and the dark shonkinite appear black, especially when the two rocks are seen in large masses.

This syenite resists weathering much better than the crumbly transition rock mentioned above, and has therefore determined the shape of curious and fantastic rock piles along the line of the outcrop. These piles commonly take the form of a mushroom or stool, in which the outspreading top is formed of the syenite, while the stem is composed of the transition rock.

The thickness of the platy white syenite is about 25 to 30 feet, and above it passes within a short space into the same coarse, crumbly transition rock that occurs below it. Here, however, the transition rock is only about 5 feet in thickness; it then passes into a coarse shonkinite like that below, which in about 5 feet begins to be denser and blacker, and in about 5 feet becomes a porphyritic rock spotted with augites and altered leucites—the same leucite-basalt as at the bottom.

The top of the laccolith is an elevated plateau, which has a marked turtle-back form and is cut in the center by the gulches which merge into the dissecting gorge. Except around this basin it is covered with the overlying sediments, but here the top of the igneous rock is exposed.

Cause of dissection.—From the presence and character of the morainal drift it is evident that during the Glacial epoch the continental ice sheet in this region pushed its way as far south as the lower slopes

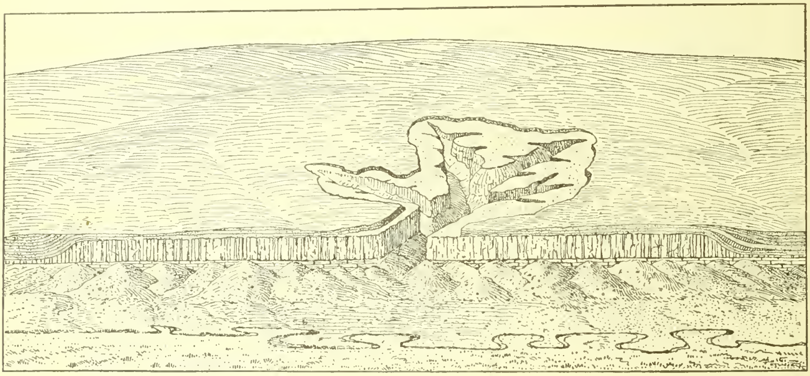


FIG. 5.—Stereogram of Shonkin Sag laccolith.

and foothills of the Highwood Mountains. The Missouri River was driven southward and forced to flow around the foot of the ice front. In doing so it excavated the valley of the Shonkin Sag and thus sawed down and through the outer circumference of the laccolith. The position of the intersecting tributary was previously determined and the ice moved over the already eroded surface of the laccolith. At the close of the Glacial epoch the river retreated to its present position, and since then erosion has deepened and extended the dissection. The relative positions of the former Missouri Valley, the laccolith, and the dissecting stream are shown in fig. 4, which represents them in a diagrammatic ground plan. In fig. 5 is given a stereogram of the laccolith, in which the various points mentioned are shown in a diagrammatic way. The dotted surface at the top represents in a general manner the area bared by erosion.

Internal structure.—From the description which has been given, it is clear that the outer portion of the laccolith is different from the

interior in character and in the type of rocks composing it. The differences may be concisely summed up in the following section, which is approximately correct:

Section of laccolith.

	Center.	Outer wall.
	Feet.	*Feet.*
Leucite-basalt-porphyry	5	10–15
Dense shonkinite	5	----------
Shonkinite	5–6	----------
Transition rock	3	----------
Syenite	25–30	----------
Transition rock	15	----------
Shonkinite	60–75	75
Leucite-basalt-porphyry	15	15
Total (approximate)	140	100

From these data a cross section of the laccolith can be constructed which will have the appearance shown in fig. 6.

FIG. 6.—Cross section of Shonkin Sag laccolith. Vertical and horizontal scales the same; white indicates syenite and transition rock; black indicates shonkinite.

In fig. 6 the vertical and horizontal scales are the same, and the sheet-like or flattened shape of the laccolith is shown. The transition rock and the syenite are shown in the white portion of the section. Their vertical thickness is known, but their horizontal extension is from necessity largely conjectural, since there is known only the distance from the center to the outer cliff wall, as revealed in the dissecting gulch.

The writer's conception of the laccolith and the structural relation of its interior parts would be represented by the figure of revolution which would be generated if the cross section were revolved upon a perpendicular drawn through its middle point. It is true this would cause the laccolith and the successive shells and syenite kernels to be also circular, to have a common center, and to become a true circle in ground plan. It is not known that this is exactly the case. The laccolith, the interior shells, and the kernels may be more or less ellipsoidal or irregular in outline. They probably do not have exactly common centers and the same thickness everywhere. Nevertheless, these are mere details which are believed to be of little importance in comparison with the idea that the figure would express the generally circular, concentrically zonal arrangement of the parts.

The discussion of the bearing of these conclusions on theoretical petrography and the origin of the various rock types is deferred until a later chapter.

PALISADE BUTTE.

Palisade Butte is less than 2 miles west of Square Butte. It stands isolated upon the open country, and forms, like Square Butte, a prominent landmark. It rises about 800 feet above the plain, and its outline against the sky resembles the weathered stump of a tree. On all sides is a long talus slope, in great part covered with soil and grass and broken here and there by low outcrops and masses of rock, which leads up with increasing gradient from the plain to the bare cliffs of massive rock which compose the main mass. Above these cliffs are again steep slopes interrupted by cliffs.

The walls are remarkable for the regular columnar structure of the rock. The hexagonal columns are, on an average, about 18 inches in diameter, though often greater, and divided by regular cross joints. Where they occur they extend the whole height of the exposures, in places a distance of 100 to 150 feet, but it is evident that originally they must have extended through the whole of this portion of the igneous mass, as in the Shonkin Sag laccolith, and therefore may have been several hundred feet in length. Their character is shown in Pl. IV, *A*, from a photograph by Mr. Weed.

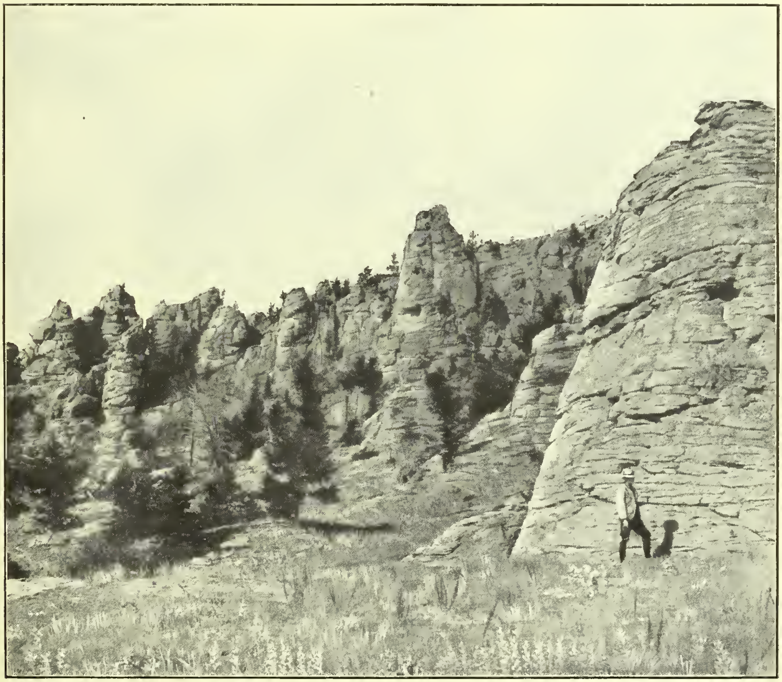
The rock composing the columnar portion of the butte and the outcrops in the talus is shonkinite. On exposed surfaces it weathers to a dark color, giving the cliffs a somber and gloomy character.

The butte is crowned at the top by a large mass of a light-colored rock of platy, laminated character. This is an augite-syenite, much like that in the Shonkin Sag laccolith. It weathers with a lighter color than the shonkinite on account of the preponderance of feldspar over augite, and the contrast between the two, while not pronounced, is striking.

The mass of syenite, which has a considerable thickness, is roughly wedge-shaped, with a cliff of some height toward the south and a slope toward the north. On the south side the rock, with its platy horizontal parting, is clearly seen resting on the massive columnar shonkinite, but toward the north the relations are less clear, because the butte to a great degree loses its precipitous character and slopes down in talus masses toward the plain, with the broken-down rock masses intermingling.

Rock variation in Palisade Butte.—The rock composing Palisade Butte shows the same variation as that found in Square Butte and the Shonkin Sag laccolith, only it is not so sharply expressed. In the low outcrops which rise through the talus slopes and are farthest from the butte the rock is very rich in augite and therefore dark and femic like that of Square Butte. As one approaches the butte an increase in feldspathic components is observed, and the rock of the columnar

A. COLUMNS OF SHONKINOSE, EAST SIDE OF PALISADE BUTTE.



B. VIEW IN ZONE OF EROSION MONOLITHS, SQUARE BUTTE.

cliffs is perceptibly different from that of the lower outcrops. In the syenite of the platy mass on top this difference is, of course, much more marked; the rock is not so strikingly salic as the syenites of Square Butte and the Shonkin Sag laccolith, but it is still a syenite.

Thus the same order holds as in the other laccoliths—a basic outer and lower mass, and above a more feldspathic upper inner portion. There has been, therefore, the same kind of differentiation as in the other laccoliths, only it is more gradually expressed.

Laccolithic character of Palisade Butte.—The position, structure, and rock relations show that Palisade Butte is a remnant of a laccolith formerly of greater size.

It is to be noted that a heavy dike of dark femic rock of monchiquoid habit (shonkinose) runs out from the eastern side toward Square Butte. As shown elsewhere, this dike has the same chemical character as the shonkinite, of which the greater part of the butte is composed. It is thus possible that this dike may have been the source of the igneous material, especially since the present mass is evidently only a remnant of a much greater one which formed the original laccolith. In this connection it may be observed that the sedimentary beds of the plain on this side are hardened and toughened, with fragments and patches of black, dense femic rock, which may possibly be remnants of the laccolithic floor in this direction.

SQUARE BUTTE.

Introductory.—In size and conspicuous position Square Butte is the most important of the laccoliths of the area. That it was known to the early explorers may be inferred from the remarks quoted in the historical summary given in the beginning of this bulletin. The exploratory work of Davis and Lindgren evidently did not lead them in this direction, since they give no description of it. Previous to the former paper by Mr. Weed and the author, the only article relating to Square Butte of which the writer has any knowledge is one by Lindgren and Melville,[a] in which is given a petrographic description of material collected there by Dr. C. A. White. The butte is described as being composed of a light-gray eruptive rock having a distinct lamination, with several sheets of a dark volcanic rock intruded in the sediments around its base. This is presumably from a note furnished the authors by Doctor White, who had passed under its base a number of years before, while on a trip collecting fossils in company with the late Prof. Jules Marcou.

General description of Square Butte.—Square Butte is a circular mass resting on the point of the table-land at the junction of the Arrow Creek and Shonkin Sag valleys. The platform consists of nearly horizontal shales and sandstones, which on three sides are

[a] Am. Jour. Sci., 3d ser., vol. 45, 1893, p. 286.

deeply trenched by stream gulches descending from the base of the butte into the larger valleys below. On the western side an open plain stretches from the base of the butte toward Palisade Butte and the breccia foothills of the main mountain group. It is the dominating feature of the scenery in this part of the region, and forms a prominent landmark from the open level country to the north and east, its dark base and white crown making it conspicuous for a long distance. Its name is derived from its flat top.

The trenched table-land on which the butte rests has a height of 4,000 feet above sea level, and the mass of igneous rock rises 1,700 feet above its pediment, making the altitude of the upper surface about 5,700 feet. The slopes are at first gentle, but become steeper, and at the top, on all sides, is a precipice perhaps 200 feet high. In a few places this escarpment is cut by small, narrow gulches. The summit is nearly level, elliptic in outline, and nearly 1 mile across in its greatest length.

The symmetric form of the butte is rather remarkable. It presents from nearly every point the appearance of a very short section of a huge cylinder resting on a low, broad, truncated cone. This regular arrangement is interrupted only on the southwest side, where a short tongue-like protrusion of the mass occurs.

Laccolithic origin of Square Butte.—Square Butte is composed entirely of igneous rock. Above the sandstones of the table-land no sedimentary rock whatever is seen. Near the immediate contact of the igneous rock with the sedimentary strata the sandstone beds curve up sharply on all sides. Below this, where the trenching by the streams has gone on, the sandstones have been cut into and the intrusive sheets which form a peripheral fringe around the mountain are brought to light. These relations are shown on the map, Pl. III, and in the cross section, fig. 8.

The form of Square Butte, the ring of upturned sediments around it, and details of structure, which will be presented later, make it evident that the butte is a laccolith stripped of its sedimentary cover, but not yet sufficiently eroded to lose its general form. This interpretation of its origin is also supported by the occurrence to the east of Square Butte of the laccoliths in the Shonkin Sag previously described.

Lower zone of dark monoliths at Square Butte.—Square Butte, from every point of view, presents, first, a base of dark, somber slopes, extending nearly halfway to the summit, which in turn are capped by light-colored ones that over great areas are often white. From a distance of a few miles the dark base is seen to be fantastically eroded into jutting towers and spires of rock. This series of strangely shaped monoliths, which surround the lower slopes of the mountain on all sides, die out at about a given height. Above this fringe of pinnacles are seen the white upper slopes, composed of masses and walls of rock which are in marked contrast to the black base.

As one approaches nearer and enters the region of black monoliths, it is found to be a maze of small, partly wooded glens, separated by towering masses and pinnacles of rock which have a height of from 100 to 150 feet in many places and of but a few feet in other places. The attention is immediately arrested by a peculiar and regular platy structure. The masses of rock are built of a series of inclined disks, each a few inches in thickness and oval to subangular in shape, with rounded edges which accentuate the disk-like form. Generally the disks decrease in size from bottom to top, but there are exceptions to this rule, and in these cases strange and weird figures are produced. The plane or hade of the disks is not horizontal, but inclines to the outside in all directions around the mountain, approximately parallel to the prevailing slope, which, indeed, is determined by this platy parting. Their character may be seen in Pl. IV, *B*, which is reproduced from a photograph by Mr. Weed.

The disposition is precisely like the dip and strike of sediments in a domed anticline, and the resemblance at times to sedimentary strata is striking.

Upper zone of white rock at Square Butte.—The monoliths are found over a distance of a mile up the slope. They diminish in size as one goes upward, and a horizon is reached where the rock changes abruptly from the dark, nearly black augitic phase to the white syenite described by Lindgren. In many places the monoliths continue higher, but are made of the white rock. They are smaller in size, but possess the same remarkable disk-like, platy structure, and the disks are perfectly parallel to those of the black variety below.

The transition line between the two rock varieties is extremely abrupt, but it is not of the nature of a contact. The even grain continues throughout, but in the space of a few inches or a foot or so the black augite begins to diminish and finally disappears, hornblende occurs, the rock assumes a more feldspathic character, and rapidly passes into the syenite which was described by Lindgren and which constitutes the main inner mass of the mountain. There is thus a narrow mottled zone between the black and the white rocks.

The monoliths which lie near the transition zone are sometimes black disks resting in place on white rock below; the transition band sometimes passes through them and they are black disks resting on white ones, or it passes through the disks almost vertically, so that one part of each disk is white and the other black.

The facts just presented are to be carefully noted, because they show that however much the two varieties of rock may differ and however abrupt may be the change from one into the other, they were not formed by two separate intrusions, but on the contrary are a geologic unit, and that the mass as a whole was intruded at one and the same time, and cooled and crystallized under the same conditions,

and that the explanation of the peculiarities which it presents must be sought in another way—one which has an important bearing on theoretic petrology.

As one approaches the top no more black rock is seen; the remainder of the mass is of white or pinkish syenite and presents everywhere the same even grain. The same platy structure continues, and at times there are no talus slopes, vegetation, herbage, or even soil, only smooth, white surfaces of naked rock, on whose almost polished slopes it is impossible to climb. Toward the top the average thickness of the plates increases somewhat and their dip gradually becomes less, until eventually they are horizontal. The ring-shaped precipice which forms the top has been caused by breaking off of the horizontal plates. The regularity of this platy jointing, together with the even rounding of the corners through weathering where the joint planes cross, gives a likeness to colossal masonry in the upper walls.

Origin of the platy parting at Square Butte.—From what has already been said in regard to the platy parting which forms so marked a feature of Square Butte, it will be seen that it bears the same relation to the mass as a whole as do the enfolding leaves of an onion to the bulb cut in half by a horizontal plane.

The parting planes are thought to represent parting surfaces parallel to the former covering of the laccoliths, from which the isothermal planes of cooling descended into the mass. The writer can conceive of no other hypothesis which would give a reasonable explanation of their arrangement and disposition; and since Square Butte is unquestionably an intrusive mass, they are regarded as one of the strongest proofs of its laccolithic nature.

Such an arrangement of the parting planes of a cooling igneous mass is by no means unknown, however, as it frequently occurs in the great phonolite domes of central Europe. Ramsay[a] has also described a similar kind of parting in the great mass of alkaline syenitic rocks of Umptek, in the peninsula of Kola, in Russian Lapland, which he regards as of laccolithic character. He also attributes this parting to the fact that the cooling planes caused shrinkage parallel to the outer cover of the mass. He also believes that between the rock layers thus formed later injections of magma of different composition have been forced, like intrusive sheets in sedimentary strata.

Johnston-Lavis,[b] in a short criticism of the former paper on Square Butte by Mr. Weed and the writer, suggests that this parting is not due to shrinkage caused by cooling, but to initial shearing stresses which were due to the forcing of a viscous mass into its present position and which are like that which produces the well-known lamination observed in many lava flows of highly siliceous magmas. This view the writer can not accept, because this platy parting parallel to

[a] Fennia, II, No. 2, 1894, p. 81.

[b] Brit. Assoc. Adv. Sci., Rept. Liverpool Meeting, 1896, p. 792.

the upper outer surface is extremely common both in intrusive masses of all kinds of igneous rocks and in cases where the magmas must have been very fluid at the time of movement and shearing stresses could not therefore have occurred in them. In many cases such masses have at the top a platy parting, which grows thicker below and finally changes to the columnar parting in conformity with the law that the initial major parting takes the direction of least resistance. The mass in which is the celebrated Fingals Cave, and the Shonkin Sag laccolith, previously described, are examples, and if Square Butte were deeply dissected by erosion toward its center it might show an outer platy parting and a deeper inner columnar one. Palisade Butte offers strong evidence on this point, as it has the same structure and thus unites all these three laccoliths together into a similar group. In view of the various stages of dissection in the different laccoliths, it being least in Square Butte, and of the facts just presented, there is no good reason for assuming that the platy parting of Square Butte was produced otherwise than by the usual and well-known one of contraction due to cooling. Square Butte is the largest, cooled the most slowly and regularly, and therefore possesses the platy parting with the most regularity.

The fact that the same parting planes pass through syenite and shonkinite alike is also strongly opposed to the view that they are due to a shearing lamination. And, moreover, since the general study of all the facts presented by these three laccoliths has led to the belief, as shown elsewhere, that the two kinds of rocks found in Square Butte have been produced by differentiation after the intrusion of the magma in a homogeneous condition, it is also believed that the magma was then in a far too liquid condition to have permitted shearing stresses to be set up within it.

Diagrammatic section at Square Butte.—It has been already said that the study of the Shonkin Sag laccolith has caused the writer to modify in some degree his conception of what is the probable interior constitution of Square Butte. The same facts are also to be seen in a less pronounced degree at Palisade Butte, but until after the Shonkin Sag laccolith was studied their true significance was not understood. Square Butte supplies the key and unites all the laccoliths in one group. As the laccoliths are in different stages of dissection, each supplies evidence that is wanting in the other two.

In the previous published section, which may in a simplified form be seen in fig. 7, the syenite was given a very great volume, and the transition zone was placed at the bottom of the laccolith, thus making it consist chiefly of this rock. At that time the conception as to the relative amounts of the two rock types was wholly theoretical, the dissection being no greater than the diagram indicates. Since, however, all three laccoliths consist of the same kinds of rock, i. e., similar magmas intruded near one another at the same time and under simi-

lar conditions, and since they are of similar structure, so far as shown by erosion, it is reasonable to conclude that they are essentially similar throughout, though they may differ in minor details of form, size, completeness of differentiation, etc. This being the case, the writer now believes that shonkinite comprises the greater part of

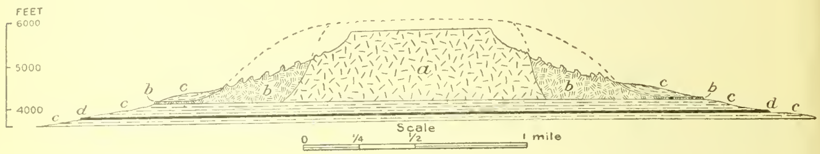


FIG. 7.—Former section through Square Butte. *a*, Syenite; *b*, shonkinite; *c*, sandstone and shale; *d*, underlying sheet. Dotted line shows restoration of laccolith. Vertical and horizontal scales are the same.

Square Butte and underlies the syenite as in the other two laccoliths, and that the relations of its parts are correctly shown in fig. 8. In this connection the geologic map should be consulted.

The protrusion to the southeast on a projecting rock tongue also confirms the above hypothesis, as it shows the shonkinite below, with

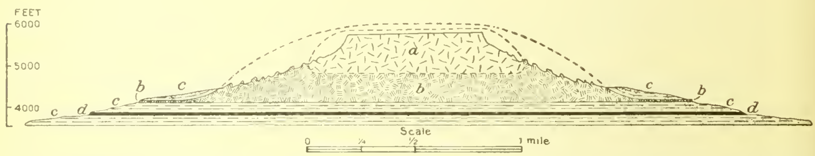
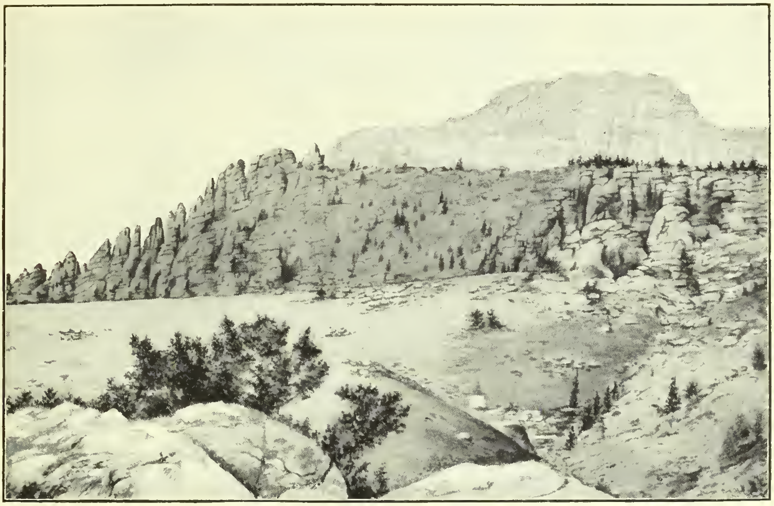


FIG. 8.—New section through Square Butte. New line. *a*, Syenite; *b*, shonkinite; *c*, sandstones and shales; *d*, underlying sheet. Dotted lines show restoration of laccolith. Vertical and horizontal scales are the same.

white syenite above, as seen in Pl. V, *A*, from a photograph by Mr. Weed.

Consideration of the bearing of these facts on the question of the origin of the laccoliths and their relation to the other igneous rocks of the Highwoods is deferred to the last chapter, on the petrology of the area.



A. PULASKOSE (SYENITE) RESTING ON SHONKINOSE, SOUTHWEST SIDE OF SQUARE BUTTE.

B. EAST END OF SHONKIN SAG LACCOLITH.

CHAPTER V.

THE SEDIMENTARY PLATFORM.

INTRODUCTORY.

The sedimentary beds on which the extrusive masses of the mountains rest, and which are cut by the intrusive rocks (see Pl. III), have been described by Mr. Weed in the Fort Benton folio of the Geologic Atlas of the United States. The part of his description which relates to the area shown on the map is here quoted, in order to show the character of the material in which the igneous rocks were intruded. The nature of the sediments has so often influenced the manner in which these intrusions took place that this is an important part in the discussion of the latter. The beds are all Cretaceous.

Cascade formation.—The Cascade formation consists of alternating beds of sandstones and shales. The lowest bed of sandstone, 160 feet thick, is distinguished from the underlying Ellis sandstone [top of the Juratrias] by its dull brownish color, its weathered appearance, and its lamination. Above these sandstones is the coal seam, which in some places occurs near the top of the formation. The sandstones lying immediately beneath it are impure, micaceous, and of a lavender tint. The coal seam is from 5 to 12 feet thick. A massively bedded sandstone that caps the coal seam and forms a sloping table-land over large areas is taken as the top of the formation. The total thickness on Belt Creek is 520 feet. * * *

The fossil leaves found with the coal seam are of Lower Cretaceous age and resemble those of the Kootanie formation of Canada.

Dakota formation.—The Dakota formation consists of beds of sandstone alternating with red and gray shales and clays. Certain purplish sandstones are of variable composition, carrying large amounts of purplish and red shale in streaks or disseminated through the rock. Buff-colored sandstones are purer and are often cross bedded. Some sandstones pass horizontally into clays, and these and the interbedded clays are mostly of a reddish or lavender color, containing lumps of yellow sandy material. At a horizon 140 to 300 feet above the coal of the Cascade formation the red shales contain bowlders and lenses of limestone varying from a few inches to a foot or more in thickness. The rock is dense, blue gray in color, weathering light buff, and contains numerous fresh-water fossils. The sandstone above these fossil-bearing beds is assumed to be the uppermost bed of the formation, giving a total thickness of about 300 feet along Belt Creek.

Colorado formation.—The Colorado formation consists chiefly of leaden-gray shales. The base is not readily separable from the Dakota, as the sandstones of that formation become shaly toward the top and alternate in their layers with the dark clay shales of the Colorado formation. The Colorado comprises two formations, previously distinguished as the Benton shale and the Niobrara limestone. The former is typically developed about the town from which it is named [Benton on the Missouri, about 20 miles north of the Highwoods]; the latter is also a shale formation in this quadrangle, but contains limestone concretions. * * * [In] the Belt coal field the Benton shale consists of alternating strata of gray

shale and impure shaly sandstones, a good section of which is seen in Belt Butte. At this locality and along the south base of the Highwood Mountains the formation holds a white ash bed whose rock resembles porcelain and breaks into shaly fragments. The sandstone over this ash bed contains fish-scale impressions, and 100 feet beneath it is a sandstone bed which generally holds pebbles of a black chert. * * * West and south of the Highwood Mountains it [the Benton] consists of dark-gray or black shales in beds 50 to 200 feet thick, alternating with yellowish, rather massively bedded sandstones. * * *

Eagle formation.—The Eagle formation * * * consists of a sequence whose most prominent bed is sandstone. The whiteness of the formation is in marked contrast to the dark-gray shales above and below it. The formation consists at the base of thinly laminated sandstones stained light brown by lignitic material and containing concretions and nodular masses of iron ore. These beds grade upward into a pure white sandstone which * * * forms extensive bluffs 75 to 100 feet high. * * * Exposures * * * occur in the bluffs of Arrow Creek and northeast of Square Butte, where its thickness is 235 feet. At these localities the beds are nearly level or but slightly tilted and their relation to the leaden-gray Colorado shales beneath is clearly seen. * * * Fresh-water shells are found in white sandstone beds in the Highwoods [a] which may represent the formation, but the strata are flexed and disturbed, while the species identified are forms commonly found in the Laramie. The beds on Arrow Creek are clearly capped by a conformable series of marine beds 2,000 feet in thickness, which are in turn overlain by the Laramie to the east (of the map).

Montana formation.—The Montana formation is composed principally of leaden-gray clay shales which are much like those of the underlying Colorado. The formation contains much sandstone interbedded with the shales in the Highwood Mountains. * * * The subdivisions of the Montana recognized farther east are not found here, and it is doubtful whether the top of the formation exists within the limits of the Fort Benton quadrangle.[b]

Summary.—On top of these formations are bench gravels and alluvium in the stream bottoms, and over a part of the area outside of the foothill country there is spread the continental glacial drift and till, carrying bowlders from distant sources. The total thickness of the sediments in this area, as given by Mr. Weed, is as follows:

Thickness of sedimentary rocks near Highwood Mountains.

Surficial materials	variable.
Montana	1,200–1,600
Eagle	235
Colorado	1,850
Dakota	180
Cascade	500

This gives a total thickness of from 4,000 to 4,500 feet of soft sandstones and shales of the character described above. These strata are weak, unresistant, and easily ruptured, and without doubt this fact has had great influence in determining the character of the intrusions and the great number of dikes which in the Highwoods form so marked a feature of the structural geology. Except for local disturbances in the mountains, the beds are horizontal or nearly so.

[a] That is, in the mountain area itself.—L. V. P.

[b] Consequently it is not found in the area shown on the accompanying geologic map (Pl. III).—L. V. P.

CHAPTER VI.

PETROGRAPHY.

INTRODUCTION.

The Highwood Mountains have proved a very interesting field for the petrographer. Some of the rock types that they have furnished have proved of importance in systematic petrography, and all of them are more or less novel in character and their study and description has added to the theoretic side of the science. Rosenbusch[a] early called attention to the importance of the igneous rocks of central Montana, and in concluding his brief report upon the Highwoods in 1885 Lindgren says: "Future examination will doubtless reveal rich harvests to the petrographer in the Highwoods and in the mountains of the upper Musselshell River." The truth of this remark has been shown in his own paper on the syenite of Square Butte and the various memoirs on this region published by Mr. Weed and the writer, and it will receive, we believe, a further illustration in the present work.

The field can not be considered, however, as exhausted. The expenditure of the amount of time necessary to make complete collections for petrographic purposes would not have been warranted under the circumstances by the results to be attained. Without doubt, in the future, petrographers will find many matters of interest which were overlooked or only touched upon in the necessarily rapid field work. It is believed that the larger features of importance which the district affords and which tend to the elucidation of the many problems of petrology that confront the student of igneous rocks have been discovered and are sufficiently treated in the present work.

Most of the analyses here given have been already published in Bulletin No. 228 of the United States Geological Survey, with very brief notes or lists of their minerals and under the provisional field names first used by the author. Those who have used the analyses will find no difficulty in recognizing them in the present work.

Summary of Lindgren's petrographic work.—Lindgren[b] regarded the Highwoods as the basement complex of an old volcano whose pipes and dikes had resisted erosion and given form to the moun-

[a] Mikr. Phys. Mass. Gesteine, 3d ed., 1895, p. 128.

[b] Tenth Census, vol. 13, pt. 15, Mining Industries, 1885, pp. 724–730.

tains. In describing the rocks petrographically he divides them into trachytes and basalts. Since they are considered post-Cretaceous in age he does not directly classify them as syenites and other granular rocks, but, following the prevailing usage of that time, he placed them under the headings mentioned above, and considered the granular types he met as the equivalents of syenite, etc. It should be recalled that at that time the age distinction with respect to igneous rocks still held a strong position with the leading systematists.

Under the trachytes three types are described: (*a*) Coarse granular, (*b*) porphyritic with feldspathic groundmass, and (*c*) porphyritic with a strongly augitic groundmass. The first type, so far as one can judge, seems founded on the syenite (pulaskose) of Highwood Peak. The second is clearly a description of the highwoodose (tinguaite var. highwoodite) of the great dike, about 1 mile north of Highwood Gap, in the valley bottom. The augite he describes rather fully, and considers it to be the same throughout the whole range of Highwood rocks. A series of specimens are then briefly described, in which there is a gradual increase in the ferromagnesian components, especially the augite, until they become dark basaltic types or basalts with sanidine instead of plagioclase. The appearance of olivine in these is noted. This progression brings us to the third type, with strongly augitic glassy groundmass. These are dense dark-green or gray rocks, with phenocrysts of augite, feldspar, and nosean (or analcite), and isotropic groundmass full of augite needles. Of these types just mentioned no locality is given, but from the general course of the party through Highwood Gap they appear to have been collected in this part of the mountains, and would seem to be some of the basaltic dikes of this part of the area. The last type appears to be a rock of tinguoid habit, judging from Lindgren's description and his correlation of it with a Judith Mountains type, where rocks of tinguoid appearance (judithose) are common, as described by the writer. In this case it can be referred to the tinguaite (pulaskose) of South Peak, as described later.

Lindgren's account of the Highwood rocks is concluded by a rather full description of the analcite-basalts, the first announcement of this interesting group. This was followed by a later paper dealing especially with them and discussing the origin of the analcite, which is held to be of primary origin. This part of his work on the Highwood rocks will be referred to in detail later, when the analcite rocks are discussed.

Previous work of the author.—As mentioned in the bibliography of the Highwoods, several papers dealing with particular phases of the rocks or descriptive of special types have been published by the writer, with field notes upon the occurrences by Mr. Weed. In this report that material has been drawn upon so far as is necessary to

give completeness to the work, and the results of additional study and correlation will be added.

CLASSIFICATION.

For purposes of petrographic description the Highwood rocks will be classified according to their geologic mode of occurrence. It is admitted at the outset that this represents no scientific system of classification, since by it things quite diverse in a petrographic sense might be brought together. Under the head of dikes, for instance, might be included rocks of all kinds mineralogically and rocks of granular, porphyritic, and even glassy texture. The classification is made solely for convenience in local use and reference. According to this classification, the rocks will be divided into the rocks of the stocks, of the laccoliths, of the dikes and sheets, and of the extrusive flows and breccias. They are named and described according to the new system of classification devised by the author and others,[a] and it is hoped that the work will serve as an illustration of the use of this system. According to it, the following classes, orders, rangs, and subrangs are represented in the Highwood Mountains:

Rocks represented in Highwood Mountains, according to new classification.

Class.	Order.	Rang.	Subrang.
Persalane	Canadare	Pulaskase	Pulaskose.
Dosalane	Austrare	Dacase	Adamellose.
	Germanare	Umptekase	Highwoodose.
		Monzonase	Monzonose.
		Andase	Shoshonose.
	Norgare	Laurdalase	Fergusose.
		Essexase	Borolanose.
Salfemane	Fortugare	Wyomingase	Montanose.
		Monchiquase	Shonkinose.
			Monchiquose.
	Kamerunare	Kamerunase	Cascadose.
	Bohemare	Albanase	Albanose.

To one acquainted with the new system and its precise definition of magma units this assemblage of subrangs gives a general idea of Highwood magmas and rocks and their genetic relations with one another that it would be difficult to convey except by long descriptions.

Since this new system is as yet hardly old enough for petrographers to have become thoroughly acquainted with it, the rocks in the following descriptions are also given the usual names; the reader will thus be able to make comparisons between the systems and to correlate the

[a] Cross, Iddings, Pirsson, and Washington, Quantitative Classification of Igneous Rocks, Chicago, 1903.

types with those of other regions. According to the prevailing systems the rocks to be described are as follows:

Rocks represented in Highwood Mountains, according to prevailing classification.

GRANULAR ROCKS.

Syenite, Augite (Albany type of Rosenbusch). Highwood Peak.
Syenite, Augite (basic type approaching shonkinite). Middle Peak.
Syenite, Sodalite. Laccoliths.
Syenite, Nosean (new type). Intrusive near Highwood Gap.
Monzonite. Highwood Peak.
Shonkinite. Shonkin stock and the laccoliths.
Shonkinite (with leucite). East Peak and Shonkin stock.
Missourite. Shonkin stock.
Fergusite (new type of leucite rock). Arnoux stock.

PORPHYRITIC ROCKS.

Syenite-porphyry (Highwood type). In dikes.
Trachyte-porphyry (hornblende-bostonite-porphyry?). In dikes.
Tinguaite-porphyry (Highwood type). In dikes.
Trachyandesite (latite). In flows and breccia.
Minette (Highwood type). In dikes and sheets.
Analcite-basalt (monchiquite). In dikes and flows.
Pseudoleucite-basalt. In dikes, sheets, and flows.

PETROGRAPHY OF STOCKS AND LACCOLITHS

GRANO-PULASKOSE (SYENITE VAR. PULASKITE) OF HIGHWOOD PEAK.

A light-colored feldspathic rock composes the southern half of Highwood Peak in its upper portion and extends in talus slides and outcrops down to the southwest. It has a jointing which produces large, heavy slabs several feet long and a foot or more in thickness, which are best seen on the summit of the peak, where they occur in the rather massive outcrops. At this point the rock is very light colored, almost white, with a pinkish to pale brownish tinge. Lower down on the southwest in the gulches and southward on the divide the color changes to a light smoke gray.

Megascopic characters.—In the hand specimen the white rock from the top is clearly seen to be almost wholly composed of feldspar having a tabular development, which gives the rock a trachytic habit. This is not so noticeable in the gray variety, which is more granitoid in character. Both varieties are dotted somewhat sparsely with ferromagnesian minerals, pale-green diopside, or glittering biotite in small crystals. In the rock at the top these minerals are in many places dull and lusterless or changed to little masses of limonite. The feldspar tables, which are the chief components, give cross sections which average about 8 mm. in length by about 2 mm. in breadth, and show the granularity of the rock. In the gray variety

they are not so long and the fabric is more like that of a common granite.

Microscopic characters.—Under the microscope there are seen in the sections the following minerals: Iron ore, titanite, apatite, diopside, hornblende, biotite, alkali feldspars, quartz, and secondary muscovite, kaolin, calcite, and chlorite.

Iron ore in small formless grains is rather uncommon and occurs usually with the diopside. The titanite and apatite are also rare. They occur generally in small masses, the apatite having the form of short prismoids.

The diopside is partly in small stout prisms, partly in very small scattered grains, and has a clear, very pale-green color without pleochroism. It has a well-marked but not perfect prismatic cleavage and a wide extinction angle, approaching 45°. The computation of the rock analysis given beyond (p. 63) shows its approximate composition to be that given below.

An analysis of a pyroxene from Edenville, N. Y., by Hawes[a] is quoted for comparison:

Composition of diopside from Highwood Peak and pyroxene from Edenville, N. Y.

	I.	II.
SiO_2	52.8	51.05
Al_2O_3	--------	2.02
Fe_2O_3	--------	1.30
FeO	10.2	12.28
MnO	--------	.12
MgO	12.4	10.02
CaO	24.6	22.07
Ignition	--------	.34
Total	100.0	99.10

I. Diopside from Highwood Peak.
II. Pyroxene from Edenville, N. Y.; analysis by Hawes.

This is placed at the end of the diopside group by Dana.[b] The proportion of the different molecules is $12MgCaSi_2O_6$ to $5FeCaSi_2O_6$, and it therefore clearly belongs to the diopsides rather than to the hedenbergite group.

The diopside is altered in many places to a fibrous green hornblende, and the latter is also occasionally found alone; but unaltered cores of the diopside remaining in many of the bundles of hornblende

[a] Am. Jour. Sci., 2d ser., vol. 16, 1878, p. 397.
[b] System Mineralogy, 6th ed., p. 359.

show the original mineral. The hornblende does not appear to be anywhere original.

An ordinary brown biotite is present in small amount. It is more abundant in the rock forming the lower southern slopes of the peak than at the top, and is often bleached or changed to a chlorite.

Of the dark-colored minerals the diopside is by far the most abundant, the others in comparison being limited in amount. In some areas these ferromagnesian components are partly changed to chlorite.

The feldspars are all alkalic, as proved by their optical properties and by the study of the analysis, which shows all the lime demanded for the diopside. They are developed tabular on m (010), and the cleavage parallel to c (001) is very pronounced. Between crossed nicols they are very nonhomogeneous; are watered, waved, or moiré in appearance; have perthite bands and included masses of a somewhat higher birefringence, and these areas and masses pass in spots into albite with distinct albite twinning. In some specimens it is difficult to find an area which appears really homogeneous, but in such a section normal to the obtuse positive bisectrix, and hence approximately parallel to b (010), the direction of extinction $\mathfrak{a}$ is 13° from the trace of the good basal cleavage (001) on b (010) and lies in the positive obtuse angle β. Hence the feldspar is a soda orthoclase, and the large extinction angle would, in a general way, indicate a high content of soda. This is confirmed by the analysis, which shows that in general the feldspar content is in the proportion of Or_1Ab_2.

While in some specimens the feldspar is fresh and clear, in others it is muddy and clouded with kaolin leaves, and when this occurs the nonhomogeneous aspect disappears, though whether this is merely an accident or there is some relation by which the more homogeneous feldspar suffers this change more easily could not be determined.

White mica is present in the rock from the top of the peak. This is seemingly of secondary origin, in part after biotite, in which case it is in large crystals, and in part after feldspar, when it is in small nests and rosettes in the feldspar. Its amount at times may be considerable.

In the rock at the top some quartz occurs filling fine angular interspaces between the feldspars. In the grayish variety along the south slopes it disappears, and the specimens taken here were tested chemically to ascertain if a small amount of nephelite might not be present, but without result. In one section an area of calcite was observed filling an angular interspace between feldspars in the same manner that Hawes[a] observed in the hornblende-syenite from Columbia, N. H. This is probably, as Rosenbusch[b] remarks, a product of infiltration into miarolitic cavities in the rock. The texture of the syenite lends additional confirmation of this idea.

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[a] Geol. and Lithol. New Hampshire, 1878, p. 208.
[b] Mikr. Phys., Mass. Gesetine, 3d ed., 1895, p. 56.

Chemical composition.—The chemical composition of the rock is shown by the first analysis in the following table:

Analyses of pulaskose of Highwood Peak and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	65.54	65.43	66.60	66.13	60.03	64.64	68.34	1.092
Al_2O_3	17.81	16.11	15.05	17.40	20.76	16.27	15.32	.173
Fe_2O_3	.74	1.15	1.07	2.19	4.01	2.42	1.90	.005
FeO	1.15	2.85	4.42		.75	1.58	.84	.016
MgO	.98	.40	.36	.04	.80	1.27	.54	.024
CaO	1.92	1.49	2.21	.81	2.62	2.65	.92	.034
Na_2O	5.55	5.00	4.03	5.28	5.96	4.39	5.45	.089
K_2O	5.58	5.97	5.42	5.60	5.48	4.98	5.62	.059
$H_2O+110°$	.54	.39	.41	1.22	.59	.27	.30	.030
$H_2O-110°$		.19				.09	.15	
TiO_2	.11	.50	.76	.74	(?)	.51	.21	.001
P_2O_5	Trace.	.13		(?)	.07	.37	.13	
CO_2	Trace.	Trace.				.37		
F		.08						
Cl		.05				.05	.04	
ZrO_2		.11						
MnO	Trace.	.23	Trace.	.13	Trace.	Trace.	.07	
SrO					(?)	.08	.04	
BaO	(?)	.03	None.	(?)	(?)	.18	.08	
Li_2O					(?)		None.	*
FeS_2		.07						
Total	99.92	100.18	100.33	99.54	101.07	100.12	99.95	

I. Pulaskose (syenite) from top of Highwood Peak. Highwood Mountains, Montana. L. V. Pirsson and W. L. Mitchell, analysts.

II. Phlegrose (syenite) from Mount Ascutney, Vermont. W. F. Hillebrand, analyst. Bull. U. S. Geol. Survey No. 148, p. 68.

III. Toscanose (syenite, akerite) from Prospect street, Gloucester, Mass. H. S. Washington, analyst. Jour. Geol., vol. 6, 1898, p. 798.

IV.* Phlegrose (syenite, porphyritic akerite) from between Thinghoud and Fjelebua, Norway. Mauzelius, analyst. Brögger, Zeit. Kryst., vol. 16, 1890, p. 46.

V. Pulaskose (pulaskite) from Fourche Mountain, Arkansas. R. N. Brackett and J. P. Smith, analysts. Ann. Rept. Geol. Survey Arkansas for 1890, vol. 2, p. 70.

VI. Toscanose (syenite) from Hughsville, near Barker, Mont. W. F. Hillebrand, analyst. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 19.

VII. Liparose (quartzose syenite) from head of Beaver Creek, Bearpaw Mountains, Montana. H. N. Stokes, analyst. Am. Jour. Sci., 4th series, vol. 1, 1896, p. 354.

VIII. Molecular ratios of No. I.

In the prevailing systems of classifications this rock is a typical syenite, in which the silica reaches the upper limit of the group and the rock stands next to the granites. The alumina and alkalies are high, the ferromagnesian elements low, and the rock is therefore in the alkaline series of syenites. A number of analyses of similar rocks from other parts of the world are introduced for comparison, and attention will be drawn to some of them later.

Mineral composition or mode.—By considering the molecular ratios given in column VIII of the table of analyses and the minerals disclosed by the section, the rock may be shown to have the following mineral composition by weight:

Mineral composition or mode of pulaskose of Highwood Peak.

	Iron ore.	Pyroxene.	Orthoclase.	Muscovite.	Albite.	Quartz.	Calculated.	Found.
SiO_2	------	4.08	15.84	5.40	32.04	8.16	65.52	65.54
Al_2O_3	------	------	4.53	4.63	9.17	--------	18.33	17.81
Fe_2O_3	0.74	------	--------	--------	--------	--------	.74	.74
FeO	.36	.72	--------	--------	--------	--------	1.08	1.15
MgO	------	.98	--------	--------	--------	--------	.98	.98
CaO	------	1.92	--------	--------	--------	--------	1.92	1.92
Na_2O	------	------	--------	--------	5.55	--------	5.55	5.55
K_2O	------	------	4.15	1.41	--------	--------	5.56	5.58
H_2O	------	------	--------	.54	--------	--------	.54	.54
Total	1.10	7.70	24.52	11.98	46.76	8.16	100.22	99.81

The occasional biotite crystals and the small amount of hornblende may be considered with the pyroxene. All of the water has been assigned to the muscovite, whereas undoubtedly a part is hygroscopic. This makes the amount of muscovite somewhat too high, and also tends to lower the orthoclase. With these exceptions the calculation represents the composition of the rock very closely. That there is only 9 per cent of normative femic constituents in the mode shows the strong salic character of the rock.

Classification in the new system.—From the analysis of the rock previously given, its position in the new system of classification may be determined by calculation of the norm, as shown in the following table:

Calculation of norm of pulaskose of Highwood Peak.

	Analysis.	Molecular ratios	Or.	Ab.	An.	Qz.	Di.	Hy.	Mt.	Il.
SiO_2	65.54	1.092	354	534	50	111	18	25		
Al_2O_3	17.81	.173	59	89	25					
Fe_2O_3	.74	.005							5	
FeO	1.15	.016					3	7	5	1
MgO	.98	.024					6	18		
CaO	1.92	.034			25		9			
Na_2O	5.55	.089		89						
K_2O	5.58	.059	59							
TiO_2	.11	.001								1
H_2O	.54									
Total	99.92		59	89	25	111	9	25	5	1

Or	32.80	93.04
Ab	46.63	
An	6.95	
Qz	6.66	
Di	2.04	6.07
Hy	2.72	
Mt	1.16	
Il	.15	
H_2O	.54	
Total	99.65	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{93.04}{6.07}=15.3$=I, persalane.

Order, $\frac{Q}{F}=\frac{6.66}{86.38}=.077$=perfelic=5, canadare.

Rang, $\frac{K_2O'+Na_2O}{CaO'}=\frac{148}{25}=5.8$=domalkalic=2, pulaskase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{89}{59}=1.5$=sodipotassic=pulaskose.

Since the texture of the rock has been shown to be the broad trachytic one, it may thus be termed a tracho-pulaskose, which, as the fabric varies into the granitic, passes locally into grano-pulaskose.

Classification in prevailing systems.—If account be taken of the tendency of the lighter colored feldspars to assume a tabular habit, giving the somewhat broadly trachytoid texture, and of the paucity of dark minerals, the rock belongs to the pulaskite type of syenites of Rosenbusch. It does not differ markedly from the pulaskite of Arkansas, whose analysis is given in the table on page 63, except in regard to silica and alumina. It might with propriety be termed a pulaskite type of syenite with accessory quartz.

The gray variety does not show this tendency to the trachytoid structure, but is purely granitoid in type. It appears more nearly related to the akerites than to any other type of syenite given by Rosenbusch. It agrees very closely with the akerite in chemical composition, as is shown by the analyses on page 63. In whatever way it may be classified it clearly belongs in the alkaline series of syenites, which passes from the alkali-granites on the one hand and grades into the foyaite or nepheline-syenite group on the other.

PULASKOSE (SODALITE-SYENITE) OF SQUARE BUTTE.

Introductory.—This rock was very fully described by Lindgren, with analyses by Melville of material collected by Dr. C. A. White, and was mentioned in the former paper by Mr. Weed and the writer. It has become well known in the literature of petrography, and here only such details will be given as are necessary to complete the discussion of the petrography of the region and of the position of the rock in the new system of classification.

Megascopic characters.—On fresh surfaces the rock is white, often with a pale-brown or pinkish tinge. It has a very heavy jointing, and on top of the butte it often appears in huge, thick slabs several yards long. It is made up mostly of feldspars, which have lath-like or tabular forms and reach 5 mm. in length. Through it are freely sprinkled slender, black, glittering prisms of hornblende of about the same average length as the feldspar. There is not enough hornblende to detract from the light color of the rock at a distance. Small grains of a salmon or pale-brown colored sodalite are also present.

Texture.—The platy form of the feldspars gives the rock a broad trachytoid texture—that which in the nephelite-syenite characterizes the "foyaite" type of Brögger. Since the interspaces between the feldspars are not always completely filled, the rock has a more or less miarolitic habit.

Microscopic characters.—The microscope shows the following minerals present, mentioned in the order of their formation: Apatite, hornblende, orthoclase and albite, sodalite, nephelite, and analcite.

The hornblende has its prisms bounded by *m* (110) and *b* (010); terminations are wanting. It is frequently twinned on *a* (100). It is strongly pleochroic, $\mathfrak{c}$ and $\mathfrak{b}$ deep chestnut brown, $\mathfrak{a}$ yellowish brown, and absorption strong; $\mathfrak{b}=\mathfrak{c}>\mathfrak{a}$. In the outer margins it is often changed to a deep greenish color, the brown merging into the green. The angle of $c \wedge \mathfrak{c}$ is 13°. It is automorphic against the feldspathic components. A few of the hornblendes contain iron-ore grains, but these do not occur in the rock except as inclusions of this character. The hornblende is similar to the brown hornblende found in the nephelite-syenite of Red Hill and other alkalic rocks, and is near barkevikite in composition, as shown by the following analysis by Melville:

Analysis of hornblende of sodalite-syenite of Square Butte.

SiO_2	38.41
TiO_2	1.26
Al_2O_3	16.39
Fe_2O_3	3.75
FeO	21.75
MgO	2.54
MnO	.15
CaO	10.52
Na_2O	2.95
K_2O	1.95
H_2O	.24
Total	99.91

The marked feature of this hornblende is the large amount of alumina and iron it contains.

The alkali feldspars are chiefly orthoclase in lath-shaped sections, and associated with them is a certain amount of a triclinic feldspar shown to be albite. In the interstices between them is the colorless isotropic sodalite, and the study of sections from different portions of the mass shows that in addition to this component there is present a variable amount of nephelite, which in some cases is abundant and in others is nearly or wholly wanting. In Lindgren's material there was also considerable analcite, and this occurs generally. So far as can be told, the analcite appears to be wholly secondary, in part after nephelite and in part after feldspar; in the latter case it occupies bays, tongues, and areas eaten into the feldspar. The sodalite is at times partly or wholly replaced by cancrinite, and in other cases bundles of fibrous natrolite occupy angular interspaces and, judging by the manner of occurrence, are secondary after sodalite or nephelite. The sodalite and analcite were separated and analyzed by Melville, with the results given in the table on the next page.

Mineral composition or mode.—From the bulk analysis of the rock given below, and from those of its components, Lindgren calculated that its mineral composition is as follows:

Mineral composition of pulaskose of Square Butte.

Hornblende	23.00
Orthoclase	50.00
Albite	16.00
Sodalite	7.96
Analcite	3.03
Total	99.99

These results would be modified somewhat if the material studied had contained the unchanged nephelite. Lindgren remarks that the sodalite may contain some hydroxyl. The amount present is calcu-

lated at practically 8 per cent. The rock contains 0.43 per cent of chlorine, which would give 5.4 per cent in the mineral. In theory normal sodalite requires 7.3 per cent.

Chemical composition.—In the following table are analyses of this rock and of its mineral components, by Melville. An analysis of a related rock is added for comparison.

Analysis of pulaskose of Square Butte and component minerals.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	56.45	0.941	38.41	0.640	41.56	49.54	49.06
Al_2O_3	20.08	.197	16.39	.161	29.48	25.07	16.07
Fe_2O_3	1.31	.008	3.75	.023			7.92
FeO	4.39	.061	21.75	.302	.49	.40	2.41
MgO	.63	.015	2.54	.063	.15	.20	2.65
CaO	2.14	.038	10.52	.188	.49	.22	8.21
Na_2O	5.61	.090	2.95	.048	19.21	15.32	5.17
K_2O	7.13	.076	1.95	.021	.91	.89	3.18
H_2O+	1.77		.24		3.73	7.49	2.27
H_2O-					.45		
CO_2							1.21
TiO_2	.29	.004	1.26	.016			.81
P_2O_5	.13	.001					.61
SO_3							Trace.
Cl	.43	.012			4.79	1.67	Trace.
MnO	.09		.15				.98
	100.45		99.91		101.26	100.42	100.55
O=Cl	.10				1.08	.42	
	100.35				100.18	100.00	

I. Pulaskose (sodalite-syenite) from Square Butte. W. H. Melville, analyst.
II. Molecular ratio of I.
III. Barkevikite from above. W. H. Melville, analyst.
IV. Molecular ratio of III.
V. Sodalite with some analcite from above. W. H. Melville, analyst.
VI. Analcite with some sodalite from above. W. H. Melville, analyst.
VII. "Sodalite-syenite" from Schlossberg, near Grosspriesen, Bohemia. F. Hanusch, analyst. Hibsch, Tscher. Min. Pet. Mitt., vol. 21, 1902, p. 522.

Since hornblende is the only ferromagnesian mineral in the rock, it contains all the iron, magnesia, and titanic acid. The feldspars appear purely alkalic, and if so the lime is also all in the hornblende. In this case the ratio of the oxides to one another should be the same

in the hornblende analysis as in the rock analysis. These ratios are as follows:

Oxides in hornblende and pulaskose of Square Butte.

	Hornblende.	Pulaskose.	Ratio.
Fe_2O_3	3.75	1.31	2.86
FeO	21.75	4.39	4.95
MgO	2.54	.63	4.03
CaO	10.52	2.14	4.91
TiO_2	1.26	.29	4.03

The titanic acid in the hornblende was calculated from the rock analysis and can not, therefore, be taken into account. The amount of magnesia in the rock is so small that the ordinary variations of analytical work might render this ratio not very exact. The ferrous irons and the limes show close agreement, based on larger quantities, but if they are correct the ferric irons can not be. Taking everything into account, it seems probable that in either the rock or the hornblende the amount of ferrous to ferric iron has not been very correctly determined, and that the error is in the rock determination, which should be about 0.86.

Classification in prevailing systems.—This rock has been called a sodalite-syenite, and Rosenbusch, mindful of the rather small amount of feldspathoids present, has placed it under the alkaline syenites rather than in the nephelite-syenite family proper. Under this system of classification, especially if the variable nephelite and sodalite is considered, the rock forms a connecting link between the two families.

Classification in the new system.—In the new system of classification the position of the rock is seen in the next table, in which its norm is calculated from the chemical analysis. It is of interest to note that this gives 70.56 per cent of alkalic feldspar, while Lindgren's calculation gives 66 per cent, the difference arising in the 3 per cent of analcite in his calculation. The 23 per cent of hornblende of the mode is replaced by anorthite, olivine, and iron ores in the norm, making all told 18.11 per cent, the difference being due to the fact that no femic alkalic constituents appear. This furnishes an excellent example of how the same oxides may be shifted to produce quite different mineral molecules, so that under a given set of conditions the oxides forming the usual component minerals may be united to form a single constituent differing in character from all of them.

Calculation of the norm of pulaskose of Square Butte.

	Analysis.	Molecular ratio.	Or.	Ab.	An.	Ne.	So.	Co.	Ol.	Mt.	Il.	Ap.
SiO_2	56.45	0.941	0.456	324	70	24	36		31			
Al_2O_3	20.08	.197	76	54	35	12	18	2				
Fe_2O_3	1.31	.008								8		
FeO	4.39	.061							49	8	4	
MgO	.63	.015							13			
CaO	2.14	.038			35							3
Na_2O	5.61	.090		54		12	24					
K_2O	7.13	.076	76									
TiO_2	.29	.004									4	
P_2O_5	.13	.001										1
Cl	.43	.012					6					
Rest	1.29											
Total	100.35		76	54	35	12	6	2	31	8	4	1

Or	42.26	89.86
Ab	28.30	
An	9.73	
Ne	3.41	
So	5.96	
Co	.20	
Ol	5.91	8.72
Mt	1.86	
Il	.61	
Ap	.34	
Rest	1.29	
Total	99.87	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{89.86}{8.72}=11.3=$ I, persalane.

Order, $\frac{\text{L.}}{\text{F.}}=\frac{9.37}{80.31}=0.11=$ perfelic $=5$, canadare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{166}{35}=4.7=$ domalkalic $=5$, pulaskase.

Subrang, $\frac{K_2O'}{Na_2O}=\frac{90}{76}=1.2=$ sodipotassic $=$ pulaskose.

Comparison with related types.—When it was believed that this rock contained sodalite as its only feldspathoid (lenad component) it stood in a class largely by itself. The fact that it contains nephelite, however, renders it akin to the other alkali-feldspar rocks which contain small amounts of this mineral. It is thus closely allied with the brown hornblende-bearing rock of Red Hill, described by Bayley,[a] which contains a rather limited amount of nephelite and some sodalite. In the very able and valuable memoirs of Hibsch upon the interesting rocks of the Bohemian Mittelgebirge, brought out in recent years, he describes a "sodalite-syenite," the analysis of which is given for comparison. The similarity, however, ends with the sodalite, since its composition, as shown by Hibsch, is the same as that of the essexite of the Rongstock, and it appears indeed questionable if in any system of classification which takes account of the relative quantities of the minerals, rocks so rich in ferromagnesian components should be classed with the feldspathic syenites.

[a] Bull. Geol. Soc. America, vol. 3, 1892, p. 231.

TRACHO-HIGHWOODOSE (NOSEAN-SYENITE).

Occurrence.—This rock occurs as a dike or small intrusive mass in the Cretaceous strata south and somewhat east of South Peak, in the foothills and between two small head branches of Byrnes Creek. With the small scale and somewhat generalized character of this portion of the map, it is impossible to locate it more definitely. On the day it was discovered the country was covered with dense smoke from forest fires, which made it impossible to take bearings by which its position could be accurately given, and the necessities of the work did not permit of a second visit to this locality.

Megascopic characters.—The weathered rock is a light brownish gray and has a somewhat cellular structure, owing to the relief caused by tabular feldspars arranged in trachytoid texture which have resisted weathering better than the other elements. Such sections attain lengths of from 2 to 5 mm.

On a freshly fractured surface the rock has a clear gray color with something of an olive tone, and the individual constituents are not very clearly contrasted. With the lens it is seen that the white feldspars are dotted through and through with tiny dark-green specks and prisms of a ferromagnesian mineral, while the interspaces between them are filled with a much larger proportion of ferromagnesian grains. An occasional flake of biotite is also seen.

Under the microscope the following minerals are seen: Iron ore, apatite, titanite, pyroxene, biotite, alkali feldspar, nosean, kaolin, and probably analcite.

Microscopic characters.—The iron ore is in small octahedrons, and is rather sparing in amount. Apatite, which is rare, is in short, thick prisms. Biotite is strongly pleochroic and shows slight peculiarities which recall its characters in the minettes; the outer border is deeper colored than the interior, and the crystal form is embayed or repeated. It is a comparatively rare component, as is also titanite, of which a few scattered crystals were seen.

The pyroxene shows considerable diversity of character; it is usually present in slender prisms which reach a maximum length of 2 mm. In a few cases short, stout columns were noted. The larger crystals are composed of a pale-green diopside with high extinction angle and strong birefringence. Toward the periphery they assume a darker green from admixture of the ægirite molecule, and are here a transition between ægirite-augite and diopside. Their outline is very apt to be beaded in the section by small attached grains of iron ore. In some places they are changed into a yellowish serpentine substance. In a few cases, especially in the vicinity of nosean, the augites become much richer in ægirite and pass over into ægirite-augite. The smaller microlites are much more apt to be darker colored, and in some cases, especially in the interspaces enriched

in soda, they pass over into ægirite, or if of diopside the end projecting into the nosean is of ægirite. This is similar to the occurrence of such pyroxenes in the phonolite of Cripple Creek as described by Cross[a] and in the analcite-basalt of the Little Belt Mountains described by the writer.[b] These small pyroxenes are neither numerous enough nor small enough to give the tinguaitic aspect, but in some of the interspaces they are rather thickly crowded. A somewhat similar structure of a syenite rock with thickly scattered small diopside prisms has been described by the writer from the Little Belt Mountains, Montana.[c]

The orthoclase feldspar which makes up over half of the rock is in tabular crystals that produce the trachytoid structure so common in the alkalic rocks. It is somewhat kaolinized in places. It contains also at times the albite molecule by means of which it passes into soda orthoclase, or it may contain microperthite intergrowths with albite. The size of these feldspar tables as seen in the section is about 2 mm. long by 1 mm. broad.

In the angular interspaces between these feldspars there is a clear colorless isotropic mineral of low refractive index. This is generally sprinkled through with the pyroxene microlites previously mentioned. It does not show any other positive characters by which it might be identified, and might be taken for glass if the character of the rock and its mode of occurrence did not utterly preclude such an idea.

Chemical composition.—At first this substance was believed to be analcite, like that of the analcite-syenite from the neighboring Little Belt Mountains[d], but when treated with dilute nitric acid the powdered rock gelatinized readily, and the acid solution after being filtered gave a strong reaction for sulphuric anhydride SO_3 and a mere trace of chlorine. Carefully treated with very dilute hydrochloric acid, the test for SO_3 gave the same result. The SO_3 did not come, therefore, from oxidation of metallic sulphides, but from a soluble sulphate. The powdered rock gives but little water in the closed tube. The chemical tests show that a considerable amount of nosean must be present in the rock, and it must be a part of the colorless isotropic substance. Some analcite is probably present, and is perhaps indicated in places where the isotropic substance is particularly clear and limpid. In such spots a rough cubic cleavage can be seen, and at times faint optical anomalies. Here, also, some particles of calcite are found, in one case with distinct crystal form. It seems probable that the analcite is secondary after the nosean. A test by the method

[a] Geology of the Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 35.

[b] Petrography of the Little Belt Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 546.

[c] Ibid., p. 468 (No. 643).

[d] Ibid., p. 469.

recommended by Osann[a] for distinguishing nosean from other minerals of the feldspathoid group, by using acetic acid and barium chloride on the section, was partly successful; some areas had $BaSO_4$ deposited upon them, while others remained clear.

No complete chemical analysis of the rock was undertaken, as it did not appear fresh enough to warrant the labor, but a partial one

Actual mineral composition or mode of tracho-highwoodose from near South Peak.

Units measured.		Volume, per cent.		Specific gravity.				Weight, per cent.
Or	819	58.93	×	2.6	=	153.2	=	53.6 orthoclase, albite.
No	100	7.20	×	2.2	=	15.8	=	5.5 nosean.
Di	329	23.67	×	3.3	=	78.1	=	27.3 diopside.
Ac	28	2.01	×	3.5	=	7.0	=	2.3 ægirite.
Bi	12	.86	×	3.0	=	2.6	=	.9 biotite.
Mt	50	3.60	×	5.2	=	18.7	=	6.4 magnetite.
Ap	25	1.79	×	3.2	=	5.7	=	2.0 apatite.
Cc	14	1.00	×	2.7	=	2.7	=	.9 calcite.
Tn	13	.94	×	3.3	=	3.1	=	1.1 titanite.
Total	1,390	100.00				286.9		100.0

by Dr. W. F. Hillebrand will be given later. However, the rock appears to be a fair subject for microscopic analysis by Rosiwal's method, and this was undertaken, with the above results. Under ægirite is understood those pyroxenes which were deep green and pleochroic. Chance brought several titanites in the measured lines, and the amount may be rather high. To reduce this to a chemical composition it is arbitrarily assumed that at least 10 per cent of albite is present, the biotite is divided into 5 parts of leucite and 4 of olivine, the pyroxenes are united, and their mass composition assumed to be that of a very similar one from the soda granite of Kekekabic Lake,[b] whose composition is known. Making these assumptions, the chemical composition may be figured from the mineral analysis given in the above table. The titanic acid appears rather high, and there is probably a more even relation in the iron oxides. The computed analysis is reckoned, of course, on a water-free basis. That it represents closely the composition of the rock is evident from its agreement, first, with the partial analysis by Doctor Hillebrand and, second, with the chemical analyses of closely related rocks of the area. These facts may be seen in the table on the next page, where all the analyses are given with water and traces omitted:

[a] Neues Jahrb. für Min., 1892, vol. 1, p. 222.
[b] Am. Geol., vol. 11, 1893, p. 385.

Chemical composition of highwoodose calculated from mode.

	Or.	Ab.	Lc.	No.	Di.	Ol.	Mt.	Il.	Ap.	Cc.	Tn.	Total.
SiO_2	28.20	6.87	0.28	1.86	15.75	0.17					0.34	53.47
Al_2O_3	8.02	1.95	.18	1.58	.70							12.43
Fe_2O_3					2.74		3.45					6.19
FeO					1.52		1.55	0.66				3.73
MgO					2.79	.28						3.07
CaO					5.27				1.11	.50	.35	7.23
Na_2O		1.18		1.44	.78							3.40
K_2O	7.37		.11		.11							7.59
TiO_2								.74			.45	1.19
P_2O_5									.84			.84
SO_3				.62								.62
CO_2										.40		.40
Total	43.6	10.0	.5	5.5	29.6	.4	5.0	1.4	2.0	.9	1.1	100.16

Analyses of highwoodose and related rocks.

	I.	II.	III.	IV.	V.	VI.
SiO_2	53.47	53.98	52.05	51.75	51.94	0.891
Al_2O_3	12.43		15.02	14.52	15.78	.122
Fe_2O_3	6.19		2.65	5.08	4.07	.039
FeO	3.73		5.52	3.58	3.17	.051
MgO	3.07		5.39	4.55	3.48	.077
CaO	7.23		8.14	7.04	6.04	.116
Na_2O	3.40	3.94	3.17	2.93	3.44	.055
K_2O	7.59	7.39	6.10	7.61	7.69	.081
TiO_2	1.19		.47	.23	.39	.015
P_2O_5	.84		.21	.18	.59	.006
SO_3	.62	.38	.02		.29	.008
CO_2	.40	.64				.009
Total	100.16					

I. Microscopic analysis of highwoodose (nosean-syenite). L. V. Pirsson, analyst.

II. Partial chemical analysis of highwoodose (H_2O; 1.92; Cl. 0.03). W. F. Hillebrand, analyst.

III. Chemical analysis of borolanose (basic syenite) from Middle Peak, Highwood Mountains, Mont. E. B. Hurlburt, analyst.

IV. Chemical analysis of fergusose (fergusite) from head of Shonkin Creek, Mont. E. B. Hurlburt, analyst.

V. Trachiphyro-borolanose (syenite-porphyry) from dike at head of Shonkin Creek, Mont. W. M. Bradley, analyst.

VI. Molecular proportions of I.

In the analysis of the rock under description, as well as in the others, the general characteristic of the Highwood rocks—the concurrent high lime and potash—is clearly seen.

Classification in the new system.—From the analysis derived from the mode of the rock may be calculated its norm and place in the new classification.

Calculation of norm of highwoodose from near South Peak.

	Analysis.	Molecular ratio.	Or.	Ab.	No.	Qz.	Ac.	Di.	Mt.	Il.	Ap.	Wo.
SiO_2	53.47	0.891	486	150	32	23	24	160				16
Al_2O_3	12.43	.122	81	25	16							
Fe_2O_3	6.19	.039					6		33			
FeO	3.73	.051						3	33	15		
MgO	3.07	.077						77				
CaO	7.23	.116						80			20	16
Na_2O	3.40	.055		25	24		6					
K_2O	7.59	.081	81									
TiO_2	1.19	.015								15		
P_2O_5	.84	.006									6	
SO_3	.62	.008			8							
CO_2	.40	.009										
Total	100.16		81	25	8	23	6	80	33	15	6	16

Or	45.04	65.20
Ab	13.10	
No	5.68	
Qz	1.38	
Ac	2.77	33.97
Di	17.38	
Wo	1.86	
Mt	7.66	
Il	2.28	
Ap	2.02	
CO_2	.40	
Total	99.57	

Class, $\frac{\text{Sal}}{\text{Fem}}=\frac{65.20}{33.97}=1.9=$ II, dosalane.

Order, $\frac{\text{L}}{\text{F}}=\frac{5.68}{58.14}=.09=$ perfelic $=5$, germanare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{130}{0}=\infty=$ peralkalic $=1$, umptekase.

Subrang, $\frac{K_2O'}{Na_2O}=\frac{81}{49}=1.673=$ dopotassic $=$ highwoodose

The norm does not differ essentially from the mode, the main difference being in the splitting up of 27 per cent of alferric augite into 17 per cent of diopside and 10 per cent of femic and salic minerals. The rock has then in essence a normative mode. It is in the lower end of dosalane, not far from salfemane, and is clearly perfelic and in rang peralkalic. In subrang it is just within the border that separates highwoodose from ilmenose. Hence it differs somewhat from the type highwoodose from Highwood Gap, as may be seen by reference to the

analysis of that rock, and approaches closer to salfemane, being much higher in lime, iron, and magnesia.

The texture is one common in granular rocks, consisting mainly of alkalic feldspars, a broad trachytoid one, produced by their lath shape, which, since it is megascopic, is designated "tracho" in the new classification. Thus the rock may be termed a "tracho-highwoodose." The rock is rather fine grained, and its appearance and character tends to show that it had crystallized rather quickly and in small mass and belongs to the "hypabyssal" types.

Classification in prevailing systems.—In the prevailing systems of classification this rock would be termed a "nosean-syenite," which is a distinct and rare member of the foyaite family. Osann[a] has shown that nosean occurs in the granular intrusive rocks of this family in the same manner as nephelite and sodalite, and has the same function. Hackmann[b] has shown its presence in nephelite-syenite of Umptek, in Kola Peninsula.

In the above occurrences this mineral accompanies nephelite, which is the dominant feldspathoid; but in the present instance no nephelite has been seen. It is possible that some of the analcite is secondary after nephelite, but it seems more probable that it is after nosean. The nosean-syenite in that case would be an equivalent to the sodalite-syenites of the Montana region described by Lindgren[c] and Merrill.[d]

GRANO-SHOSHONOSE (MONZONITE) OF HIGHWOOD PEAK.

Introductory.—This rock, whose field occurrence has been described in the discussion of the geology of Highwood Peak, has, as related, a somewhat different facies in different parts of its mass. The main type occurs next to the white pulaskose (pulaskite) forming the southwest part of the peak or intruded stock, and extends as the main portion of the mass until it merges into the fine, dense type of the north slopes and border.

In the outcrops the rock appears very dark, a deep stone color. At a distance it is almost black and in striking contrast with its neighbor, the white pulaskose. Under the hammer it is tough and breaks with difficulty, there being no tendency toward jointing on a small scale. It is fresh and yields excellent specimens.

Megascopic characters.—Examined on a freshly fractured surface, the rock is a dark stone gray with much the appearance of many rather fine-grained diorites or gabbros. It is composed of a mixture, in about equal parts, of blackish ferromagnesian and white feldspathic minerals. The average size of grain is from 1 to 2 mm. in diameter.

[a] Neues Jahrb. für Min., 1892, vol. 1, p. 222.
[b] Kola, Fennia, II, No. 2, 1894, p. 121.
[c] Am. Jour. Sci., 3d ser., vol. 45, 1893, p. 286.
[d] Proc. U. S. Nat. Mus., vol. 18, 1895. p. 671.

None of the minerals exhibit any crystal form, but occasionally there can be seen the brilliant surface of a small particle of biotite.

Close examination shows also that former joints have been recemented by material of a feldspathic nature, injected after their formation. This phenomenon is discussed in a later paragraph.

Microscopic characters.—In thin sections the following minerals are found: Iron ore, apatite, biotite, diopside, labradorite, and soda orthoclase. The apatite is in the usual small, stout prismoids; the iron ore in small anhedra, generally associated with the biotite.

The pyroxene does not show any good crystal outlines, being in rough prismoids and grains. It has a pale-green color, and in places shows a faint but perceptible pleochroism, indicating probably a slight admixture of the ægirite molecule; in one instance a large anhedron has a perfectly colorless core. There is clearly not enough of the ægirite molecule in the mixture to classify the pyroxene as an ægirite-augite; it belongs in the diopside group, since a section of it cut nearly parallel to *b* (010) gives $c \wedge \mathfrak{c} = 40°$. The thickness of the section, as shown by the feldspars, is about 0.03 mm., and the interference color is yellow of the second order, showing a maximum birefringence of 0.030. These are the properties of diopside. The mineral is spongy and incloses a large amount of iron ore and biotite. It is occasionally twinned on *a* (100). It is of a type common in the Highwood rocks.

The plagioclase is rather thickly scattered in the interspaces between the pyroxenes in rather small, short laths, ranging from 0.2 to 0.4 mm. in length. The laths are usually twinned according to both the albite and Carlsbad laws, and measurements according to Michel Lévy's method, in the zone perpendicular to *b* (010), show them to be labradorite of the composition $Ab_1\ An_1$; thus in one section the symmetrical extinctions of the albite twins are 9°, of the Carlsbad half 25°; the section is therefore that of a labradorite $Ab_1\ An_1$ cut about 42° from (100), or nearly parallel to the face *y* (201), and in covergent light the section shows the bisectrix α nearly centered in the field.

The mineral of final consolidation is the alkali feldspar, which is in broad, shapeless plates, inclosing the labradorite laths in a poikilitic manner. In this respect it recalls the rock of Monte Mulatto figured by Brögger,[a] but the plagioclase laths are smaller and more nearly like the type of Yogo Peak.[b] A section of the alkali feldspar was found parallel to *b* (010) and showing the obtuse bisectrix $\mathfrak{c}$. The cleavage parallel to *c* (001) was excellent, and a parting parallel to *a* (100) or *m* (110) permitted the orientation of the section, the angle between the two being 66°, while *a* (100) on *c* (001)=angle β is 63° 54′. The bisectrix α lies in the obtuse angle β; it is therefore positively

[a] Predazzo, 1895, p. 56.

[b] Pirsson, L. V., Petrography of Little Belt Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 476.

inclined and is 9° 30′ from the trace of *c* (001). These characters show that the mineral is a soda orthoclase or soda microcline (anorthoclase), the angle of extinction being that given by Fouqué for anorthose.[a] It may be added that the rock appears very fresh and without any alteration products.

Behavior with acids.—When the powdered rock is boiled with very dilute nitric acid, filtered, and the filtrate evaporated, a considerable amount of gelatinization ensues, indicating a mineral which yields to the acid.

Olivine has not been seen in the sections, although it may occur sporadically in the rock. The very small amount of chlorine, all of which is needed by the apatite, shows that not more than a mere trace of sodalite could be present. Nosean is also excluded by the test for SO_3, giving a negative result. Moreover, no isotropic material has been found in the sections, which confirms the above tests and also excludes analcite and leucite. Leucite, which is decomposed by acids, does not give gelatinous silica. From all this it is concluded that nephelite is probably present in a small amount in the rock, though it has not been found with certainty in the sections. It must be at any rate limited in amount, and, if present, plays an insignificant rôle. It will be noted that it occurs in the calculated norm.

Chemical composition.—The chemical composition of this rock is shown in the following table. Included in the table are analyses of several other rocks of similar characters, from localities in Montana, which have been described in previous publications. There is added an analysis of the monzonite from Monzoni given by Brögger and of a Swedish rock classed by him as a monzonite. It will be seen that the Highwood rock has similar features in its chemical composition, the rather low silica, rather high alumina, lime, iron and magnesia, moderate alkalies, and potash predominating over soda.

[a] L'étude des feldspath: Bull. Soc. Fran. Min., vol. 17, 1894, p. 148.

Analyses of shoshonose of Highwood Peak and related rocks.

No.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	51.00	54.42	52.81	54.20	50.35	52.05	52.80	56.25	0.850
Al_2O_3	17.21	14.28	15.66	15.73	15.76	15.02	19.99	20.50	.169
Fe_2O_3	2.41	3.32	3.06	3.67	2.32	2.65	3.63	1.85	.015
FeO	4.23	4.13	4.76	5.40	7.30	5.52	3.40	4.23	.058
MgO	6.19	6.12	4.99	3.40	7.40	5.39	3.20	2.54	.155
CaO	9.15	7.72	7.57	8.50	10.12	8.14	4.22	3.62	.164
Na_2O	2.88	3.44	3.60	3.07	2.75	3.17	3.10	5.91	.047
K_2O	4.93	4.22	4.84	4.42	3.89	6.10	7.74	4.80	.052
H_2O+	.63	.38	.93	.50	.45	.35	1.18	.83	------
H_2O-	------	.22	.16	------	------	------	------	------	------
TiO_2	.13	.80	.71	.40	.30	.47	1.00	.63	.001
P_2O_5	.33	.59	.75	.50	.39	.21	.70	------	.002
SO_3	.03	------	Trace.	------	------	.02	------	------	------
Cl	Trace.	------	.07	------	------	.24	------	------	------
Fl	------	------	Trace.	------	------	------	------	------	------
MnO	Trace.	.10	Trace.	.70	.35	Trace.	------	------	------
BaO	.34	.32	.24	------	------	.42	------	------	------
SrO	.14	.13	.09	------	------	.28	------	------	------
Total	99.60	100.19	100.24	100.50	101.38	100.03	100.96	101.16	------

I. Shoshonose (monzonite) from Highwood Peak, Montana. E. B. Hurlburt, analyst.

II. Monzonose (monzonite) from Yogo Peak, Little Belt Mountains, Montana. W. F. Hillebrand, analyst. Am. Jour. Sci., 3d ser., vol. 50, 1895, p. 473.

III. Monzonose (monzonite) from stock at head of Beaver Creek, Bearpaw Mountains, Montana. H. N. Stokes, analyst. Am. Jour. Sci., 4th ser., vol. 1, 1896, p. 357.

IV. Monzonose (monzonite) from Tyrol. V. Schmelck, analyst. Brögger, Triad. Erup. Predazzo, 1895, p. 24.

V. Kentallenose (monzonite, olivine) from Smalingen, Sweden. H. Santesson, analyst. Loc. cit., p. 46.

VI. Borolanose (basic syenite) from Middle Peak, Highwood Mountains, Montana. E. B. Hurlburt, analyst.

VII. Monzonite from Maros Peak, Borneo. Dr. Hinden, analyst. C. Schmidt in Sarasin's Celebes, vol. 4, 1901, p. 25.

VIII. Micromonzonite from Ambodimadiro, Madagascar, A. Lacroix, analyst. Roches alc. d'Ampasindava, Nov. Arch. du Muséum, 4th ser., vol. 1, 1902, p. 110.

IX. Molecular ratio of I.

Included in the table is a grano-borolanose of the neighboring Middle Peak stock. This is inserted to show how closely it resembles shoshonose in general chemical composition, the chief difference being a higher content of alkali. This difference is sufficient to produce important mineral variations, however, as shown in the description of this type.

Mineral composition or mode.—A consideration of the molecular ratios in the foregoing table and a study of the section give the following percentage composition by weight of the component minerals:

Percentage of minerals in shoshonose of Highwood Peak.

Iron ore	2
Biotite	10
Pyroxene	30
Labradorite	25
Soda orthoclase	33
Total	100

If it is assumed that the pyroxene has the same composition as in the shonkinite of Square Butte, given elsewhere; that the biotite has the same composition as the dark-green biotite of Monzoni analyzed by Rammelsberg;[a] that the labradorite is a rather acid type $Ab_4 An_3$, and that the soda orthoclase has about half as much soda as potash, as is often the case, the rock will have the chemical composition given in the following table:

Calculated and determined composition of shoshonose.

	Calculated.	Found by analysis.
SiO_2	52.2	51.0
Al_2O_3	16.7	17.2
Fe_2O_3	2.4	2.4
FeO	2.6	4.2
MgO	6.4	6.2
CaO	9.5	9.1
Na_2O	3.2	2.9
K_2O	4.7	4.9

The agreement shows that the estimated amounts of the component minerals and their assumed composition must be nearly correct.

Texture.—The texture of this rock is a normal granitic one. It is xenomorphic rather than hypautomorphic, for none of the older ferromagnesian minerals show good crystal form; only the smaller lath-

[a] Min. Chem. Erg., 1886, p. 118.

shaped plagioclases have automorphic development. The texture, indeed, is that one typical of most stocks, of which the Highwood Peak mass furnishes a small but excellent example.

Classification in the new system.—The calculation of the norm from the analysis shows that the rock is a shoshonose.

Calculation of norm of shoshonose of Highwood Peak.

	Analysis.	Molecular ratios.	Or.	Ab.	An.	Ne.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	51.00	0.850	312	114	140	56	174	55			
Al_2O_3	17.21	.169	52	19	70	28					
Fe_2O_3	2.41	.015							15		
FeO	4.23	.058					19	23	15	1	
MgO	6.19	.155					68	87			
CaO	9.15	.164			70		87				7
Na_2O	2.88	.047		19		28					
K_2O	4.93	.052	52								
TiO_2	.13	.001								1	
P_2O_5	.33	.002									2
SO_3	.03										
Rest	1.11										
Total	99.60		52	19	70	28	87	55	15	1	2

Or	28.91	66.28
Ab	9.96	
An	19.46	
Ne	7.95	
Di	19.40	31.99
Ol	8.29	
Mt	3.48	
Il	.15	
Ap	.67	
Rest	1.14	
Total	99.41	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{66.28}{31.99}=2.7=$ II, dosalane.

Order, $\frac{L}{F}=\frac{7.95}{58.33}=.136=$ perfelic $=5$, germanare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{99}{70}=1.4=$ alkalicalcic $=3$, andase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{52}{47}=1.1=$ sodipotassic $=3$, shoshonose.

Grad, $\frac{P+O}{M}=\frac{19.40}{3.63}=5.3=$ dopolic $=2$, shoshonate.

Subgrad, $\frac{(MgFeO)+CaO''}{(K_2Na_2)O''}=\frac{300}{0}=$ permirlic, 1, shoshonote.

Thus, in the new system, if the texture is considered and the classification be carried down into the grad and subgrad the rock is granoshoshonote. All that this name means, then, is indicated in the table above. Since the mode is not a normative one, and as, instead of olivine and feldspathoid molecules in the norm, biotite is actually developed in the mode, the rock may be termed a biotitic granoshoshonote. This name is a concise expression for a granular rock consisting of ferromagnesian and feldspathic minerals which has the following characteristics:

The ferromagnesian minerals are present in notable quantity, but

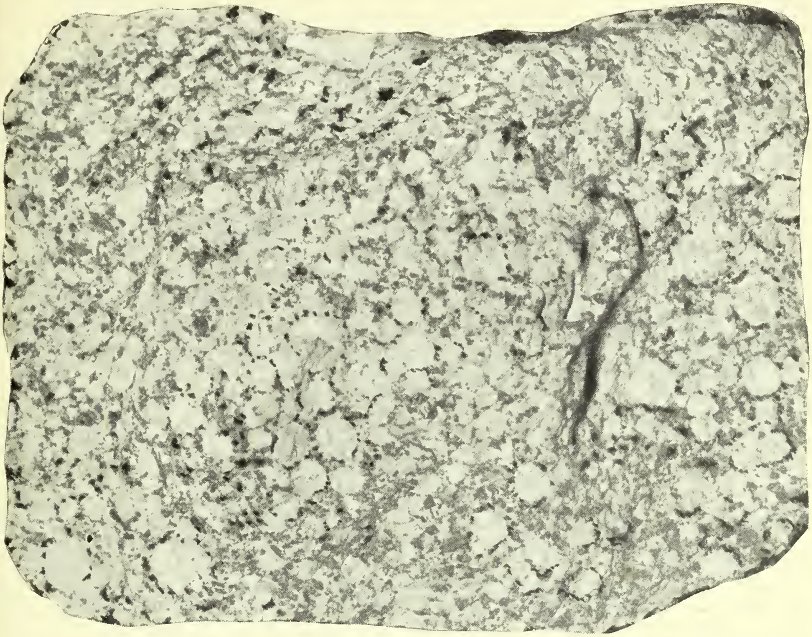
are exceeded in amount by the feldspathic minerals; the feldspars are not accompanied by any notable amount of feldspathoids; considerable anorthite is present molecularly, but is exceeded in amount by the alkali-feldspar molecules, in which the potash and soda are about equal; of the ferromagnesian minerals, the iron ores are greatly dominated by the other ferromagnesian minerals which contain few or no alkaline molecules; olivine and a feldspathoid, which might have been expected to occur in the rock, are replaced by biotite, whose amount, however, is not large, not exceeding 12.5 per cent. This name, then, surely gives a rather exact idea of the character of the rock, but it does not tell anything of its manner of occurrence, of the shape of its mass, of its relations to related rocks, and of its geologic age, for, according to the writer's belief, these things have no place in a systematic classification, although they may be of the greatest importance and of the utmost interest in other ways.

Classification in prevailing systems.—In the prevailing systems the rock is a typical monzonite both mineralogically and chemically. Since the monzonites form a group of rocks of what may be termed mean composition, they vary in different directions according to the rock complex in which they occur and with which they show affinities. In the present case the monzonite is related to the special group of alkaline rocks occurring in the Highwoods, and its genetic relationship to this particular group is shown by the presence of augite similar to that in the other members and by the occurrence of small and otherwise unimportant quantities of feldspathoid minerals. There are also other points of resemblance, but it is often as difficult to describe the minute and subtle features which indicate that a rock belongs to a certain geographic class or petrographic province as it is to portray the characteristics which distinguish one man from another.

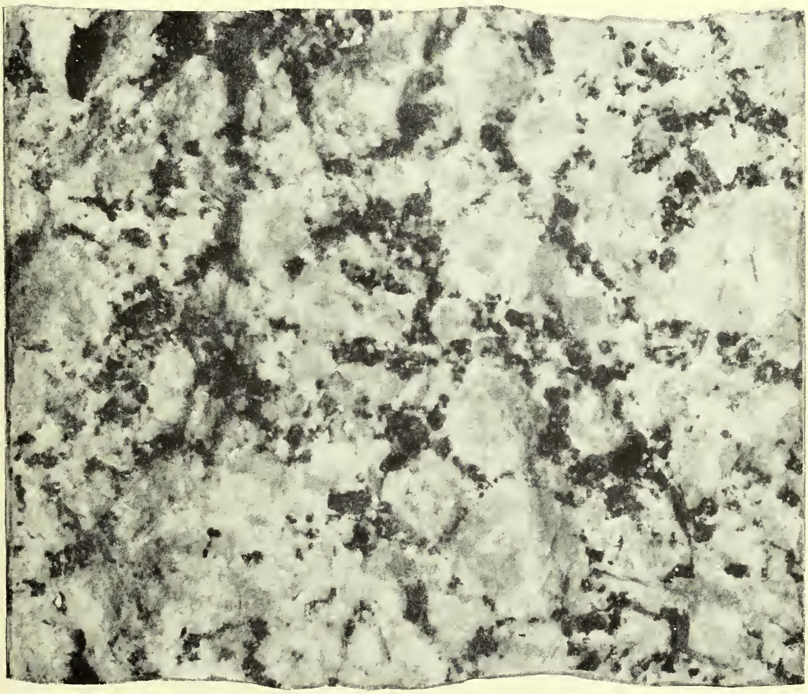
The alliance between the monzonites and certain alkaline rocks has been already pointed out by Rosenbusch,[a] and the present case adds another example to the list.

Dikelets in shoshonose (monzonite).—As previously mentioned, the surface of the rock is everywhere seamed by very fine lines of light-colored feldspathic material. This is due to veins or dikelets which have been injected into it. It appears to the writer that the only way in which these dikelets, which are very common in many granular igneous rocks, can be explained is by the hypothesis that they are later injections along joint planes formed by the contraction of the cooling rock mass. This seems confirmed also by the toughness of the rock body and its present lack of small joint planes. These previously existed, having been formed by the contraction of the cooling rock, but have been everywhere healed by a later intrusion of feldspathic material. This, on the rock surfaces, produces lines,

[a] Mikr. Phys. Mass. Gesteine, 3d ed., 1895, p. 124; Elemente der Gesteinslehre, 1898, p. 108.



A.



B.

FERGUSITE FROM HIGHWOOD MOUNTAINS.

at first glance scarcely noticeable, since the films, which have been broken across, are often as thin as paper. This healing of the initial jointing by later processes may be ascribed to pneumatolytic action, and it would seem as if the material must have been carried in by heated liquids or gases, as the width of most of the cracks is so slight that it is impossible to imagine a viscous molten fluid forcing its way along them for any distance.

Contact facies of shoshonose (*monzonite*).—As mentioned elsewhere, the main type just described passes on the north side of the mass into outcrops and rock piles of a dense, very dark, and somewhat flinty-looking variety with a platy cleavage. On exposed surfaces it weathers to a dark gray, mottled by larger mineral grains. From its relations in the field this rock is believed to be a contact form of the type described above. In thin sections it shows the same minerals, but it has a somewhat different texture. The augite is in smaller grains, but has rather better crystal form, while the feldspathic components are in very minute microlites and grains, the contrast causing the larger augites to appear like phenocrysts in a feldspar groundmass. The iron-ore grains are commonly surrounded by a thin biotite mantle. These minerals are not large enough to give the rock a porphyritic habit, and it might be called a grano-shoshonose (micromonzonite).

FERGUSOSE (FERGUSITE) OF ARNOUX STOCK.

Occurrence.—The main stock at the head of Shonkin Creek lies at the intersection of the parallel of 47° 15′ north latitude and the meridian of 110° 30′ west longitude. About 2 miles northwest of it is a much smaller stock intruded into the basaltic flows and breccias. This stock is in general circular in plan and is a little over a mile in diameter. It lies on the north slopes of the main ridge and is dissected by a ravine whose waters are tributary to Shonkin Creek. The locality was not seen by the writer, but the description of the main type composing this small stock is based on material collected by Mr. Weed.

Megascopic characters.—The general character of this type is that of a light-gray massive rock of rather coarse grain. This general color effect is given by the mingling of a pale flesh-colored component with a much smaller amount of a dark-colored one. On closer inspection it is seen that the light component is in round grains running from 5 to 2 mm. in diameter, and averaging about 3 mm. These grains are clearly of a feldspathoid mineral, and in outline they are sometimes sharply, sometimes more or less poorly, defined. In some places they are distinctly separated; in others they are closely crowded. Their general appearance is shown on Pl. VI, *A*, which presents them of natural size. In Pl. VI, *B*, they are seen on a small portion of the rock surface magnified three times. It can be plainly seen in Pl. VI,

B, that all of the light component consists of these rounded masses or of small anastamosing offsets from them. This is an important point in the classification of the rock and will be alluded to later on. As will be shown, they are pseudoleucites. The dark component which fills the interspaces between these round grains of pseudoleucite is a blackish-green augite in small irregular masses showing an occasional dull-lustered cleavage face. The largest of them are rather columnar and about 2 mm. long. Here and there at times a small bronzy-lustered plate of biotite is seen. These, intermingled and outlined in places by little stringers of feldspathoid substance, form a sort of granular interfilling between the larger pseudoleucites. This appearance is shown on Pl. VI, *B*.

Microscopic characters.—In thin sections the minerals observed are apatite, iron ore, olivine, biotite, augite, orthoclase, nephelite, and zeolites with kaolin.

The apatite is in small, stout prisms of the character usual in basic rocks. The iron ore is in small formless grains. The amount of these minerals is small. Of the olivine, only a few scattered, mostly formless grains were seen in the sections. It is fresh and of the usual character. Its amount is entirely too small for it to be reckoned as one of the normal constituents of the type; its occurrence must be regarded as sporadic. Biotite is seen in scattered shreds without crystal form. It has the usual brown pheochroic character, and only a small quantity is found.

The augite is the only ferromagnesian mineral which is important. It is of a green color and very similar to the augites which have been described as characteristic of shonkinose (shonkinites). It is slightly pleochroic in tones of green, between a slightly grayish cast and a yellowish olive. Its angle of extinction is large, about 45°, and it is clear that the diopside molecule predominates and that it is not an ægirite-augite, though probably a little of the ægirite molecule is present. In its cleavage and other characters it offers nothing of especial interest.

In plain light the areas of white feldspathoid mineral are colorless save for a brown tone here and there, caused by a partial kaolinization, which renders the material turbid. In polarized light they are neither isotropic nor do they show the characteristic twinning of large leucites. They are composed of irregular patches and rudely fibrous radiating bundles of minerals having the birefringence and properties of alkali feldspars and nephelite. They are, indeed, similar to occurrences already described from Brazil,[a] Arkansas,[b] and Montana.[c]

[a] Graeff, Neues Jahrb. für Min., 1887, vol. 2, p. 257.
[b] Williams, J. F., Ann. Rept. Arkansas Geol. Surv. for 1890, vol. 2, p. 268.
[c] Pirsson, L. V., Am. Jour. Sci., 3d ser., vol. 50, 1895, p. 395; 4th ser., vol. 2, 1896, p. 194.

The masses have a peculiar mottled, marbled effect, due to the intergrowth of the two minerals, and in a few very small spots are penetrated by clear areas of a colorless isotropic mineral which is held to be secondary analcite. In some places very small secondary feldspars with clean-cut crystal outlines seem to have formed. As the optical tests on these intermingled feldspathic minerals gave somewhat indefinite results, it was determined to confirm them by chemical tests. For this purpose a piece of the rock was broken into fine fragments and out of these was carefully picked about half a gram of material which contained only the white feldspathoid substance and in which was no dark mineral. Thus the possibility of any contaminating olivine was avoided. The fragments were reduced to powder, which was then boiled for a moment with very dilute nitric acid, the solution was filtered, and the filtrate evaporated. As the filtrate diminished in volume an abundant gelatinization ensued. The solution gave an abundant and powerful flame test for soda, showing clearly the presence of nephelite in some quantity. The solution gave no reaction for chlorine or sulphuric anhydride, which indicated that there was no sodalite or nosean present. The undissolved residue consisted of the alkali feldspars.

Chemical composition.—The complete analysis of this rock is given in the next table. The noteworthy features of it are the rather low silica and alumina, the medium iron and magnesia, and the high lime and alkalies, with the strong predominance of the potash. Analyses of some other leucitic rocks are given for comparison. The silica, it is to be noted, is rather high for a leucite rock, owing to the fact that the greater part of the original leucite has been turned into orthoclase. It is not higher, on the other hand, than the rock from Brazil or the wyomingite, but these have higher alkalies and thus a higher amount of leucite.

In III and IV, typical leucitites, as that term is now used, the general relations of the oxides is very close to those in fergusose, the higher silica being the most marked difference. It thus represents very well in a chemical way the extrusive leucitic magmas.

In regard to analysis II, it would appear as if the separation between alumina and magnesia were doubtful, since Rosenbusch[a] remarks that it contains more pyroxene than III, while the analysis would indicate an extremely small amount of pyroxene. The amount of alumina is so large as to be almost marvelous in a rock with the mineral composition as described.

The comparison with the analysis of missourite is interesting. It is at once observed that missourite is a much more basic rock; it is lower in silica, alumina, and alkalies, and much higher in lime and magnesia, the iron remaining the same. Missourite is thus much richer in augite and has abundant olivine. Fergusose (fergusite) is a

[a] Elemente der Gesteinslehre, 1898, p. 350.

Analyses of fergusose from near Shonkin Creek and leucitic rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	51.75	52.16	46.51	45.99	46.06	53.70	46.48	0.863
Al_2O_3	14.52	20.14	11.86	17.12	10.01	11.16	19.00	.142
Fe_2O_3	5.08	6.45	7.59	4.17	3.17	3.10	4.74	.032
FeO	3.58		4.39	5.38	5.61	1.21	2.30	.050
MgO	4.55	1.54	4.73	5.30	14.74	6.44	2.49	.114
CaO	7.04	4.64	7.41	10.47	10.55	3.46	4.35	.125
Na_2O	2.93	5.73	2.39	2.18	1.31	1.67	8.46	.047
K_2O	7.61	8.12	8.71	8.97	5.14	11.16	6.78	.081
$H_2O+110°$	2.25	1.39	2.45	.45	1.44	2.61	3.31	.125
$H_2O-110°$			1.10			.80		
CO_2							.36	
TiO_2	.23	Trace.	.83	.37	.73	1.92	1.22	
P_2O_5	.18	(?)	.80		.21	1.75	.15	
SO_3	Trace.	(?)	Trace.		.05	.06	.19	
Cl	.05	Trace.	.04		.03	.03	.08	
MnO	Trace.	Trace.	.22		Trace.	.04	Trace.	
BaO	.30	(?)	.50	.25	.32	.62	(?)	
SrO	.07	(?)	.16	None.	.20	.19	(?)	
Li_2O	Trace.						(?)	
Total	100.14	100.17	99.73	100.65	99.57	[a]100.21	99.91	

[a] Including traces of rare elements and deducting O=Fl=0.44 per cent.

I. Fergusose (fergusite) from Arnoux core, h ad of Shonkin Creek, Highwood Mountains. E. B. Hurlburt, analyst.

II. Janeirose (leucitophyre) from Sierra de Caldas, S. Paulo, Brazil. F. W. Dafert, analyst. Hussak, Neues Jahrb. für Min., 1892, vol. 2, p. 149.

III. Chotose (leucitite) from Bearpaw Peak, Bearpaw Mountains, Montana. H. N. Stokes, analyst. Weed and Pirsson, Am. Jour. Sci., 4th ser., vol. 2, 1896, p. 147.

IV. Albanose (leucitite) from Capo di Bove near Rome, Italy. H. S. Washington, analyst. Am. Jour. Sci., 4th ser., vol. 9, 1900, p. 53.

V. Missourote (missourite) from Shonkin core, head Shonkin Creek, Highwood Mountains. Weed and Pirsson. Am. Jour. Sci., 4th ser., vol. 2, 1896, p. 321.

VI. Orendose (wyomingite) from Leucite Hills, Wyoming. W. F. Hillebrand, analyst. W. Cross, Am. Jour. Sci., 4th ser., vol. 4, 1897, p. 130.

VII. Arkansose (leucitite) from Etinde Volcano, Cameroon Mountains, Africa. M. Dittrich, analyst. E. Esch, Sitzb., k. Preuss, Akad. Wiss., Berlin, Math. Phys. Kl., 1901, p. 299.

VIII. Molecular proportions of I.

leucocratic (salic) type in Brögger's sense, though not strikingly so, while contrasted with it missourite is melanocratic (femic); thus fergusose represents the leucitites, missourite the leucite-basalts.

In regard to the surface lavas Rosenbusch[a] says: "The two divisions of the leucite rocks, the leucitites, free from olivine, and the olivine-bearing leucite-basalts, are distinguished not alone by the presence or absence of the olivine. The typical leucitites, in contrast to the typical leucite-basalts, are characterized much more by a far smaller content in iron ores and augite." Thus in the Highwood Mountains the intrusive representatives of leucite rocks, fergusite and missourite, have the same difference.

Texture.—The texture of the rock is best seen from the photographs shown on Pl. VI. A glance at the picture of the hand specimen gives the impression that the rock is a porphyry. When the rock is examined, however, it is seen that this idea is not correct. By porphyritic texture one understands that certain minerals possess a definite well-cut crystal form and that they are embedded in a distinct groundmass. This is not the case here, for all of the leucite is in approximately rounded grains with well-defined though crystallographically not well-bounded grains of augite between them. There can not be distinguished two periods of formation of any mineral, nor two types of any mineral formed simultaneously. The structure is much more to be compared to that of certain syenites which are characterized by a tabular development of the feldspar. That is, the feldspathic minerals are dominant, and have attempted to take their own form and have approximately done so, compelling the ferromagnesian elements to crystallize in between them.

It is also to be noted that, whereas in a mineral which crystallizes in some form other than the leucitohedron and to which it tends to approximate the cross sections taken at random would have a variety of shapes, producing an effect of irregularity or of granular texture, in the case of leucite the endeavor to assume the form of the tetragonal trisoctahedron or leucitohedron results in the production of spheres or spheroids, and every cross section is either a circle or approximately one, thus tending to destroy the effect of irregularity and to produce a pseudoporphyritic structure. Aside from this, the rock has in the hand specimen the solidity, firmness of texture, and general appearance of the granitic types of rocks, as suggested by Pl. VI, *B*.

Classification in the new system.—In the new system this rock occupies a definite position in the subrangs under laurdalase, and as it is the only described analysis under this subrang its name has been given to the division.[b] This may be seen in the following calculation of its norm.

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[a] Mikr. Phys. Mass. Gesteine, 3d. ed., 1895-96, p. 1232.

[b] Cross, Iddings, Pirsson, and Washington, Quantitative Classificationof Igneous Rocks, p. 268.

Calculation of the norm of fergusose.

	Analysis.	Molecular ratio.	Or.	Ab.	An.	Ne.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	51.75	0.863	486	42	28	80	216	10			
Al_2O_3	14.52	.142	81	7	14	40					
Fe_2O_3	5.08	.032							32		
FeO	3.58	.050					13	2	32	3	
MgO	4.55	.114					95	19			
CaO	7.04	.125			14		108				3
Na_2O	2.93	.047		7		40					
K_2O	7.61	.081	81								
TiO_2	.23	.003								3	
P_2O_5	.18	.001									1
Cl	.05	.001									1
Rest	2.62										
Total	100.14		81	7	14	40	108	10	32	3	1

Or	45.04	63.96
Ab	3.67	
An	3.89	
Ne	11.36	
Di	23.75	33.50
Ol	1.53	
Mt	7.42	
Il	.46	
Ap	.34	
Rest	2.62	
Total	100.08	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{63.96}{33.50}=1.9=$ II, dosalane.

Order, $\frac{L}{F}=\frac{11.36}{52.60}=.21=$ lendofelic $=6$, norgare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{128}{14}=9.1=$ peralkalic $=1$, laurdalase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{81}{47}=1.7=$ dopotassic $=2$, fergusose.[a]

Mineral composition or mode.—The rock was too coarse grained for satisfactory measurement under the microscope, and it was therefore measured megascopically, with the following results:

	Units measured.	Volume, per cent.		Specific gravity.				Weight, per cent.
Sal	334	70.3	×	2.6	=	1,827.8	=	65.1
Fem	141	29.7	×	3.3	=	980.1	=	34.9
Total	475	100.0				2,807.9		100.0

These results agree so closely with those calculated for the norm given above that we may say that the rock has a normative mode.

Classification in prevailing systems.—In the prevailing systems of classification this rock has also a distinct place of its own and should be called fergusite. This is due to its mode of occurrence, mineral

[a] When this name was chosen it was supposed the Arnoux stock was in Fergus County. Recent maps show the locality a little north of the line, in Choteau County. Boundary lines in these thinly settled regions are not very accurately known, so the error, if it should be confirmed, is not a matter of importance.

and chemical composition, and texture. It is defined as a granular intrusive rock consisting of dominant leucite with subordinate augite. Small amounts of accessory minerals may be present, such as apatite, iron ores, biotite, sporadic olivine, etc., but the true determinants are the leucite and the augite. The rock is therefore the granular representative of the leucitites, and it bears the same relation toward them that missourite bears to the leucite-basalts, and thus fills a gap in this system of classification.

It is true that in the present example the leucite has been changed to pseudoleucite, but that does not alter the validity of the type. In a large part, probably the major part, of the missourite of the Shonkin stock the leucite is also changed to pseudoleucite, but, as mentioned under the description of missourite, in places the leucite is still left unchanged and in other places it occurs changed and unchanged in the same specimen. A detailed study of all parts of the Arnoux stock would probably show the same phenomena, or if the mass could be studied at various vertical levels it might show the same variations. In hand specimens of missourite and other altered leucite rocks of the Highwoods it is impossible to distinguish the unchanged from the altered leucite. Only when studied under the microscope does the real character appear. Therefore the type may be considered as a well-established one, although the specimen described is not a perfect unaltered example.

GRANO-BOROLANOSE (BASIC SYENITE, SHONKINITIC TYPE) OF MIDDLE PEAK.

The rock forming the Middle Peak stock closely resembles the shoshonose (monzonite) of Highwood Peak in appearance and in chemical composition. It differs from it, however, in important particulars, as will be seen in the following description. It has a border facies which varies in several respects from the main type.

Megascopic characters.—On a freshly fractured surface the rock has a medium-gray color and a moderately even grain, the individual components being in the neighborhood of 1 mm. in diameter. On inspection it is seen to be made up of light and dark minerals in about equal proportions. The light feldspathic minerals are devoid of distinct form, but the ferromagnesian component is chiefly a dark-green augite in short, stout, columnar forms without good terminations. The mingling of these two gives the rock at a short distance the general appearance presented by many medium-grained diorites.

Microscopic characters.—Under the microscope the following minerals are seen: Iron ore, apatite, biotite, olivine, augite, and alkali feldspar.

The iron ore is at present in rather abundant small grains; a few larger ones were seen. It is generally surrounded with narrow mantles of a red-brown pleochroic biotite. There are also a few

isolated shreds of this biotite, but its total amount is small and its rôle insignificant. There is a moderate amount of a rather fresh olivine present in rounded crystals which average about 0.4 mm. in diameter. In many places where it touches alkali feldspar there is a very narrow zone of a green pleochroic biotite separating them.

Two varieties of augite are present, and it is by far the most abundant ferromagnesian mineral. The first variety, which is rare, is a colorless or faintly green diopside in long, slender, well-formed prisms. It has a wide extinction angle, strong birefringence, and is often twinned on (100). The other pyroxene, the most abundant dark mineral, is an augite of a green color with a tinge of brown. It is present in short, stout prismoids and grains, and also at times in larger columns, which are well crystallized. These attain a length of 4 mm. It has a good cleavage, is nonpleochroic, and often zonally built. It has inclusions of iron ore, biotite, and brownish glass, and the largest crystals are sometimes spongy and filled with these earlier products of crystallization.

The light-colored feldspathic component appears to consist wholly of alkali feldspars. These laths are in rather thin tabular crystals which are almost always carlsbad twins. No albite or other twinning was observed. The laths do not contain any microperthite intergrowths, but are zonally built. In sections parallel to the clinopinacoid, which are easily recognized by their nearly square outlines, lack of twinning, and medium birefringence, the cleavage parallel to the base (001) is seen as a series of fine lines with moderately high power. The direction of the vertical axis is told by a rather poor prismatic parting and the arrangement of minute inclusions parallel to the prism faces. The angle between these two directions was measured at 65°, which is approximately equal to the angle β of feldspar. On such faces the bisectrix $\mathfrak{c}$ emerges and the plane of the optic axis gives an extinction angle of 5° with the base of the basal cleavage in the obtuse angle β. These properties are found in the interior of the crystals, and they show that this portion of them is composed of a rather pure orthoclase. Toward the outer boundary the birefringence gradually rises a little and the extinction angle also increases to 12° and over. This shows that the inner kernel of orthoclase gradually changes to a soda orthoclase by assumption of the albite molecule, giving rise to the zonal structure mentioned.

Between these feldspars lie the final products of crystallization—a fine mosaic of interlocking granules of alkali feldspar. These small areas have an appearance which is much like that of the groundmass of some feldspathic dike rocks or of trachytoid lavas having a microgranitic structure. They were carefully searched for quartz or nephelite, and while no quartz is present, it can not be said that

nephelite is not. Under the circumstances and considering the chemical composition of the rock, it would be natural to expect nephelite, but the grains were too fine for any definite determination, and the presence of olivine precludes the usual gelatinization test. The writer has found that gelatinization and staining with eosin is an unsatisfactory and unsafe test where minute amounts of nephelite are concerned, and it was not tried. If a safe means of determining very small amounts of nephelite mixed in with alkali feldspars could be discovered it would be of great service to petrographers.

Some of the small areas mentioned above are rounded and in plain light appear pale brown from incipient kaolinization. It is barely possible that they may be pseudoleucites, a suspicion aroused by the chemical composition of the rock.

Chemical composition.—The chemical composition of this rock is shown in I of the table of analyses on page 92.

The characteristic chemical feature is the combination of high oxides of the alkaline earths and high alkalies, and more especially of lime and potash. These give the rock a marked chemical individuality—the Highwood stamp. The alumina is moderate, the silica rather low. These characters are shared by two other rocks of the district (II, III), which will be described in a later paragraph. There is a general resembance of these types in the distinguishing features to borolanite (IV), which is also low in silica, contains a good deal of lime, and is high in potash; its alumina is no doubt too high, in part it contains P_2O_5 and probably some MgO. Another rock which is similar in the same way is that variety of the nephelite-syenite complex of Magnet Cove described by Washington, first as shonkinite and later as covite, whose analysis is given under V. In the new system of classification it falls in the same subrang. The chemical difference between these types and the shonkinoid ones is shown by comparison with the analysis of the montanose (shonkonite) of the Shonkin Sag laccolith given under VI. The lower alumina and alkalies and the larger amount of bivalent oxides produce a marked difference in the mineral composition, which is easily seen in a comparison of the hand specimens. The same is also true of the shoshonose (monzonite) of Highwood Peak; in the hand specimens, as previously mentioned, this rock very closely resembles that of Middle Peak, but the microscope shows a considerable amount of plagioclase, which is produced by the higher lime and lower alkalies, and which is wanting in the Middle Peak rock.

Analyses of borolanose and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	52.05	50.11	50.00	47.8	49.70	47.88	51.00	0.867	0.835	0.833
Al_2O_3	15.02	17.13	19.36	20.1	18.45	12.10	17.21	.147	.168	.182
Fe_2O_3	2.65	3.73	3.87	6.7	3.39	3.53	2.41	.017	.023	.024
FeO	5.52	3.28	2.67	.8	4.32	4.80	4.23	.076	.046	.037
MgO	5.39	2.47	2.18	1.1	2.32	8.64	6.19	.135	.062	.055
CaO	8.14	5.09	4.96	5.4	7.91	9.35	9.15	.145	.091	.089
Na_2O	3.17	3.72	3.63	5.5	5.33	2.94	2.88	.052	.060	.059
K_2O	6.10	7.47	8.52	7.1	4.95	5.61	4.93	.065	.080	.091
H_2O+	.35	4.47	3.53	2.4	1.09	1.52	.63	------	------	------
H_2O-	------	------	.46	------	.25	.70	------	------	------	------
CO_2	None.	------	------	------	------	.12	------	------	------	------
TiO_2	.47	.82	------	.7	1.33	.77	.13	.006	.010	.006
P_2O_5	.21	.67	------	(?)	.40	1.11	.33	.001	.005	.002
SO_3	.02	.08	------	.4	------	None.	.03	------	.001	------
Cl	.24	.07	------	------	------	Trace	Trace	.006	.002	------
Cr_2O_3	None.	------	------	------	------	.04	------	------	------	------
NiO	------	------	------	------	------	Trace	------	------	------	------
MnO	Trace.	Trace.	------	.5	Trace	.15	Trace	------	------	------
BaO	.42	.63	------	.8	------	.46	.34	------	------	------
SrO	.28	.35	------	------	------	.13	.14	------	------	------
	100.03	100.09	------	------	------	------	------	------	------	------
Cl=O	.06	.02	------	------	------	------	------	------	------	------
Total	99.97	100.07	99.18	99.3	99.44	99.99	99.60	------	------	------

I. Borolanose (basic syenite) from Middle Peak. E. B. Hurlburt, analyst.
II. Borolanose (basic syenite) from Palisade Butte. H. W. Foote, analyst.
III. Borolanose (basic syenite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst. (Partial analysis; TiO_2. P_2O_5, etc., not determined; in part with Al_2O_3, which is high.)
IV. Borolanose (borolanite) from Lake Borolan, Sutherland, Scotland. J. Hort Player, analyst. Horne and Teall, Trans. Roy. Soc. Edinburgh, vol. 37, pt. 1, 1892, p. 163.
V. Borolanose (covite) from Magnet Cove, Arkansas. H. S. Washington, analyst. Jour. Geol., vol. 9, 1901, p. 612.
VI. Montanose (shonkinite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst. (Includes ZrO_2, 0.03 and V_2O_3, 0.04.)
VII. Shoshonose (monzonite) from Highwood Peak. E. B. Hurlburt, analyst.
VIII. Molecular proportions of I.
IX. Molecular proportions of II.
X. Molecular proportions of III.

Mineral composition or mode.—In determining the actual mineral composition of the rock, it was found necessary in using Rosiwal's method to measure together the alkali feldspars and any nephelite that might be present, since, for the reasons given in the microscopic

description, it was impossible to discriminate between them. In all 4,390 units were measured in 114 measurements, giving an average of 38 units to each measured area. The following quantitative composition is derived:

Mineral composition or mode of borolanose of Middle Peak.

	Units measured.	Volume, per cent.		Specific gravity.				Weight, per cent.
Feldspar	2,465	60.25	×	2.6	=	156.6	=	53.2
Augite	1,275	28.81	×	3.3	=	95.0	=	32.3
Biotite	175	3.98	×	3.0	=	11.9	=	4.0
Olivine	60	1.37	×	3.3	=	4.5	=	1.7
Iron ore	200	4.55	×	5.2	=	23.6	=	7.9
Apatite	35	.89	×	3.2	=	28.4	=	.9
Total	4,390	99.85				294.2		100.0

Classification in the new system.—The position of the rock in the new system is given in the following calculation, which shows it to be borolanose near shonkinose. On account of its granular texture it should be called grano-borolanose.

Calculation of the norm of borolanose.

	Analysis.	Molecular ratio.	Or.	Ab.	An.	Ne.	So.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	52.05	0.867	390	84	66	52	18	218	40			
Al_2O_3	15.02	.147	65	14	33	26	9					
Fe_2O_3	2.65	.017								17		
FeO	5.52	.076						31	22	17	6	
MgO	5.39	.135						78	57			
CaO	8.14	.145			33			109				3
Na_2O	3.17	.052		14		26	12					
K_2O	6.10	.065	65									
TiO_2	.47	.006									6	
P_2O_5	.21	.001										1
Cl_2	.24	.003					3					
Rest	1.07											
Total	99.97		65	14	33	26	3	109	40	17	6	1

Or	36.14	
Ab	7.34	
An	9.17	62.94
Ne	7.38	
So	2.91	
Di	24.53	
Ol	6.23	
Mt	3.94	35.95
Il	.91	
Ap	.34	
Rest	1.07	
Total	99.96	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{62.94}{35.95}=1.8=$ II, dosalane (near salfemane).

Order, $\frac{L}{F}=\frac{10.29}{52.65}=.19=$ lendofelic $=6$, norgare (portugare).

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{117}{33}=3.6=$ domalkalic $=$ essexase (monchiquase).

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{65}{52}=1.2=$ sodipotassic $=$ borolanose (shonkinose).

It is of interest to compare the norm as calculated above with the mode obtained by measurement. For this purpose the feldspathic components of both are united under the symbol F, and ilmenite with magnetite.

Comparison of norm with mode of borolanose.

	I.	II.	III.
F	62.9	53.2	53.7
Di	24.5	32.3	33.7
Bi		4.0	
Ol	6.2	1.7	6.2
Mt	3.8	7.9	3.8
Ap	.3	.9	.3

Under I is given the norm and under II the mode. The chief difference lies in the relation of feldspar to pyroxene, and is caused by the fact that in the norm is included 9.2 per cent of anorthite. The lime silicate is, however, actually not in the feldspars but in the augite, as shown by the study of the section. If it were transferred to the augite the mode would assume the proportions seen in III and the close agreement of the ratios of feldspar to augite is seen at once. The lime may not be present in the augite exactly as anorthite, but as a closely related lime silicate.

It is interesting to observe that this relation in the feldspars makes the chief difference between this rock and the shoshonose (monzonite) of Highwood Peak. There the anorthite has united with the albite to make plagioclase; here the lime as a silicate has gone into pyroxene.

Classification in prevailing systems.—In the prevailing systems this rock does not have any very definite position. If the relative quantities of the components and its associations and chemical composition are disregarded and the fact that it consists in the main of alkali feldspars and augite is considered, it would be called an augite-syenite. There are certainly not enough feldspathoids present to place it in the nephelite-syenite family. If the basic character shown by the analysis, the relative quantities of the minerals, and its regional rock associations are taken into account, it appears as a type transitional between syenite and shonkinite, and might then be called a shonkinitic syenite.

Border facies.—At the contact the rock just described has a rather distinctly marked endomorphic contact facies. It appears to be somewhat coarser in grain and has a slight tendency to a porphyritic texture. This is due in the main to the fact that the orthoclase feldspars appear in large, thin plates of considerably greater size than in the prevailing type and tend to be roughly oriented parallel to the contact in a rude flow structure which gives the rock a slight tendency to split in this direction.

Under the microscope the minerals of the general type just described are found with some little variation. In the contact rock the iron ore and apatite, and perhaps biotite, of a rich pleochroic brown, are somewhat more abundant than in the type rock. The augite varies considerably in size and is a clearer green color, passing to a rich sea green on the border. It is, however, nonpleochroic in spite of this addition of the ægirite molecule, and hence it must still be chiefly diopside. The feldspars are in carlsbad twins, and in small angular interspaces are occasional clear isotropic areas of unaltered sodalite, whose occurrence serves to make almost certain the presence or former presence of a lenad (feldspathoid) mineral in the main type.

The main feature of this border facies is the occurrence of hornblende associated with diopside. The hornblende appears to some extent to replace the diopside, since in those places where it is abundant diopside is rare, and vice versa. It is a compact homogeneous variety, is not seen intergrown with diopside, and appears in all respects like a primary mineral. It is much like arfvedsonite in a general way, and is at all events, considering its habitat and associates, one of the alkalic group of hornblendes. It is strongly pleochroic as follows:

$\mathfrak{a}$=Ocher-yellow.
$\mathfrak{b}$=Dark olive.
$\mathfrak{c}$=Dark olive-green.

The absorption is very strong and the arrangement rather peculiar: $\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$. On account of the strong absorption, which is almost equal to a colored tourmaline, it was difficult to measure the angle of extinction on the clinopinacoid of $c \wedge \mathfrak{c}$, but it is certainly as much as 30° and probably more—a most unusual angle for a hornblende. The double refraction is rather weak. It occurs in well-shaped prisms with poor terminations. The prisms are stout rather than slender, and the prismatic cleavage is well marked.

This hornblende is unique in its characters and the writer knows of none exactly like it. It does not occur in any other rock in the Highwoods, its nearest affinity being the green variety in the sodalite-syenite (pulaskose) of Square Butte, from which it differs in color, absorption, and angle of extinction. It does not agree with any of the alkalic series described by Brögger.[a] It may be that, although of alkalic type, the preponderance of potash over soda in the magma has had some effect in producing its novel characters. Unfortunately want of time and material have prevented the writer from investigating it chemically.

BOROLANOSE (SYENITE) OF PALISADE BUTTE.

As mentioned in the geologic description, the upper part of Palisade Butte is composed of a rock which is much lighter and more feld-

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[a] Grorudit-Tinguait Serie, 1894, p. 27.

spathic than the shonkinose or shonkinite of the main lower portion. There is a gradation between the two, but the top is of distinctly syenitic character.

Megascopically the rock is medium granular, of a light-brown color, and dotted with augite. In the section the same minerals are seen as described under shonkinose—greenish augite, iron ore, apatite, alkali feldspars, and zeolites. The feldspars are in lath-like forms, which often radiate and produce rough spherulitic clusters. All the interspaces between them are filled with masses of a fibrous zeolite, which is largely natrolite. Probably nephelite or some other lenad (feldspathoid) mineral was originally present. The rock is not fresh enough to warrant more extended study, but an analysis of it was made to determine its systematic position and for purposes of magmatic comparison. This analysis is given under II of the preceding table. In regard to classification in prevailing systems, it has a position similar to the rock of Middle Peak; it could be classified as a basic syenite, though if all the zeolitic areas represent a former feldspathoid mineral, such as sodalite, it would probably fall into the nephelite-syenite family.

In the new system of classification the analysis can be calculated into a norm composed of the following standard minerals:

Or	44.48	73.76
Ab	9.43	
An	8.05	
Ne	11.05	
No	.71	
Di	10.20	20.93
Ol	2.19	
Mt	5.34	
Il	1.52	
Ap	1.68	
Rest	5.45	
Total	100.14	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{73.76}{20.93}=2.6=$ II, dosalane.

Order, $\frac{L}{F}=\frac{11.79}{61.97}=1.9=$ lendofelic $=6$, norgare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{140}{29}=4.9=$ domalkalic $=2$, essexase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{80}{60}=1.3=$ sodipotassic $=3$, borolanose.

BOROLANOSE (SYENITE) OF SHONKIN SAG LACCOLITH.

What has been said above in regard to the light-colored rock of Palisade Butte applies well to this rock in a general way. The light-colored, grayish, moderately granular rock is dotted with considerable augite and less biotite.

In the section it is seen to be composed of apatite in small, pale violet-brown crystals, some iron ore, a few scattered olivines, some biotite in long foils of a dark-brown color and strongly pleochroic, a good deal of augite, not very well crystalized, pale brown in color and with good cleavage, a large amount of alkali feldspar greatly zeolitized, and some nephelite, which is fresher than the feldspar. The nephelite and feldspar are commonly intergrown in a poikilitic manner.

The rock is too much altered by zeolitization to warrant more

extended description or a complete analysis, but to determine its affinities and for the purpose of comparing it with the associated shonkinose for reasons given in the chapter on the petrology, Doctor Hillebrand made a partial analysis, which is given under III of the preceding table. From this it will be seen that it closely resembles the rock of Palisade Butte just mentioned and also that of Middle Peak, both showing the characteristic high lime and potash of the Highwood magmas. As to systematic position in prevailing systems, it is a little difficult, in view of the zeolitization, to say whether this rock should be esteemed a basic member of the syenite group with accessory nephelite or a member of the nephelite-syenite family; probably it belongs in the latter and near the covite of Washington.

In the new system the analysis is sufficiently complete to calculate the norm and determine its position, which have been done as follows:

Or	49.48	76.01
Lc	.87	
Ne	16.76	
An	8.90	
Di	10.78	18.76
Ol	.83	
Mt	5.57	
Il	.91	
Ap	.67	
Rest	3.53	
Total	98.30	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{76.01}{18.76}=4.0=$ II, dosalane.

Order, $\frac{L}{F}=\frac{17.63}{58.38}=0.30=$ lendofelic $=6$, norgare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{150}{32}=4.6=$ domalkalic $=2$, essexase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{91}{59}=1.5=$ sodipotassic $=3$, borolanose.

In making this calculation it has been assumed, from what is known of the mineral components of the rock, and the chemical character of the Highwood rocks in general, that 0.50 per cent of TiO_2 and 0.30 per cent of P_2O_5 are present, and a corresponding amount has been deducted from the Al_2O_3. While this is probably not absolutely correct, it is certainly more nearly correct than it would have been to have left these oxides out of account entirely. The result shows that the rock, like those of Middle Peak and Palisade Butte, is borolanose, where it evidently belongs. Considering its texture, it is, then, granoborolanose.

SHONKINOSE (SHONKINITE) OF SQUARE BUTTE.

The rock composing the dark-colored lower and outer mantle of Square Butte has already become well known as the original type of shonkinite, and for convenience and completeness the original description is summarized here.

Megascopic characters.—The shonkinose of Square Butte is a dark, coarse-grained, rather crumbly rock, which is mottled by the contrast between the black augite and the light-colored feldspathic material. The augites are greenish black, columnar, well formed, and average about 30 mm. in length, being found occasionally three times as large.

Considerable biotite is seen with bronze-lustered cleavage faces, which may be 1 or 2 cm. across, with irregular borders, and composed of smaller biotites in parallel growths which inclose poikilitically the other minerals. Filling the interspaces are the white feldspathic minerals. Augite is the most predominant mineral and makes up half the bulk of the rock.

Microscopic characters.—The microscope shows the following minerals: Apatite, iron ore, olivine, biotite, augite, albite, soda microcline, orthoclase, sodalite, nephelite, cancrinite, and zeolites.

Apatite is the oldest mineral and occurs in short, stout prisms. At times it is a pale red or violet brown and nonpleochroic. Other crystals are filled in the interior with a dusty pigment and are pleochroic; ε=pale steel-blue, ω=pale leather-brown. The prisms attain a length of 0.5 mm.

Olivine has its usual characters; it is generally fresh and colorless, but at times has a reddish ferruginous border that may be an alteration into iddingsite. In thicker sections some crystals have a faint pleochroism in tones of yellow and white.

Biotite is strongly pleochroic, deep umber-brown, and pale brownish-orange. The extinction is parallel to the cleavage. Thin plates have a small opening of the cross that shows it to be meroxene. Where olivine touches orthoclase there is usually a reaction band between them of a deep-green biotite, which has very little pleochroism or absorption.

Pyroxene occurs in good crystals and, owing to the ease with which they may be detached from the matrix, excellent material can be obtained for study. Measurements on the goniometer show the following forms: *a* (100), *b* (010), *m* (110), and *s* (111). The pyroxene is somewhat tabular on *a* (100). The crystals were crushed, sifted, and separated by the silver-thallium nitrate fluid, and material of great purity obtained in this way was subjected to chemical analysis with the following results:

Analysis of pyroxene in shonkinose of Square Butte.

SiO_2	49.42
TiO_2	.55
Al_2O_3	4.28
Fe_2O_3	2.86
FeO	5.56
MgO	13.58
CaO	22.35
MnO	.10
Na_2O	1.04
K_2O	.38
H_2O	.09
Total	100.21

A consideration of this analysis shows that the mineral has almost exactly this composition: $13\,Ca\,(MgFe)\,Si_2O_6 + 2\,(Na_2R'')\,(AlFe)_2\,SiO_6$.

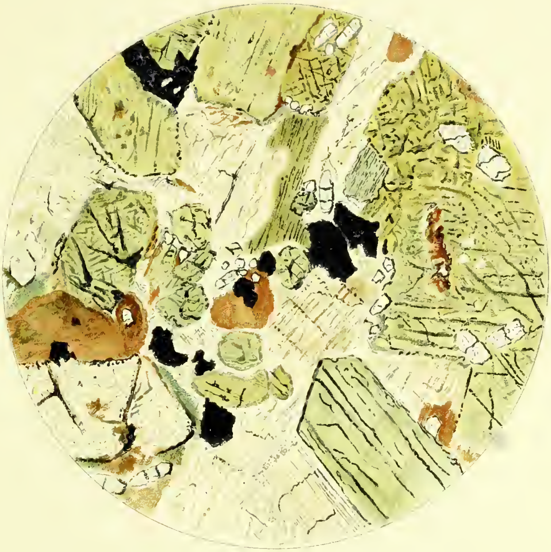
PLATE VII.

PLATE VII.

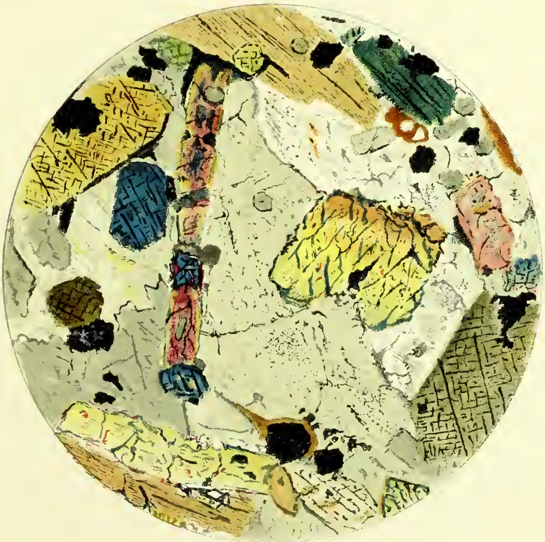
SHONKINOSE OF SQUARE BUTTE.

A. Shonkinose, Square Butte, Highwood Mountains, Montana: 18 diameters; polarized light; nicols uncrossed. Actual field, 4 mm. Apatite, iron ore, olivine, biotite, pyroxene, anorthoclase, orthoclase.

B. Shonkinose, Square Butte; 18 diameters; polarized light; nicols crossed. Actual field, 4 mm. Iron ore, apatite, biotite, augite, and orthoclase.



(A)



(B)

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SHONKINOSE OF SQUARE BUTTE

It is interesting to observe that if the analysis of this augite should be considered that of a rock, and the norm calculated, the augite would be composed of the following mineral molecules:

Calculated mineral composition of augite.

Leucite	1.74
Nephelite	4.83
Anorthite	5.84
Diopside	73.80
Akermanite	4.44
Olivine	3.81
Magnetite	4.18
Ilmenite	.91
Rest	.19
Total	99.74

In a general way this shows that the augite is greatly influenced in composition by the magma in which it is formed. This fact becomes more striking when seen in this way than by a bare comparison of analyses. It will be useful, also, to observe this calculation in making the comparison between the norm and mode of the new classification.

In thin section the augite is of a dark-green color with an olive tone, good cleavage, and occasional inclusions of iron ore. Orthoclase is the dominant feldspar. It is fresh and generally xenomorphic, occurs sometimes in rude columnar shapes, and contains inclusions of glass crystallographically arranged. The angle of the optic axes is variable, being usually small, sometimes nearly zero. In places the augite contains patches of intergrown soda microcline.

Albite is present in small amount, as shown by the specific gravity separation between 2.61 and 2.60. Qualitative analysis shows that the mineral is free from lime.

Nephelite has been found in the specific gravity separates and has been proved to be present in recent sections. It fills small interspaces, is commonly zeolitized, and the rock contains only a small amount of it.

Cancrinite was not definitely proved to be present in the sections, but was found and tested chemically in the products separated by heavy fluids.

Sodalite also occurs as an accessory mineral. It is seen occasionally in the section as a limpid isotropic filling of interspaces, but it is often zeolitized.

Natrolite occurs in fibrous patches and bundles secondary after feldspar, nephelite, and sodalite. The appearance of the rock in thin section is shown in Pl. VII, which also illustrates in a general way the character of the minerals in the Highwood rocks with femic norms.

Chemical composition.—The chemical composition of this rock is seen in the table below. Its characteristic features are the low silica and alumina, large amount of ferromagnesian oxides and lime, and the predominance of potash over soda.

Analyses of shonkinose and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	46.73	50.00	48.98	47.88	48.05	50.15	52.09	0.779
Al_2O_3	10.05	9.87	12.29	12.10	13.94	15.86	11.93	.098
Fe_2O_3	3.53	3.46	2.88	3.53	2.67	2.44	1.84	.022
FeO	8.20	5.01	5.77	4.80	5.98	5.39	7.11	.114
MgO	9.27	8.31	9.19	8.64	7.81	5.30	12.48	.232
CaO	13.22	11.92	9.65	9.35	7.25	8.40	7.84	.236
Na_2O	1.81	2.41	2.22	2.94	2.72	4.13	2.04	.029
K_2O	3.76	5.02	4.96	5.61	6.56	5.00	3.01	.040
H_2O+	1.24	1.16	.56	1.52	1.66	1.50	.35	
H_2O-		.17	.26	.70				
CO_2		.31		.12			.16	
TiO_2	.78	.73	1.44	.77	1.10	1.00	.73	.010
P_2O_5	1.51	.81	.98	1.11	1.15	.86	.34	.011
SO_3		.02		None.				
Cl	.18	.03		Trace.			Trace.	.003
Cr_2O_3		.11	Trace.	.04			.10	
NiO		.07		Trace.			.07	
MnO	.28	Trace.	.08	.15			.15	
BaO	?	.32	.43	.46			?	
SrO	?	.07	.08	.13			?	
Total	100.56	100.01	99.99	99.99	98.89	100.03	100.24	
	.04	.08	.08					
	100.52	99.93	99.91					

I. Shonkinose (shonkinite) from Square Butte. L. V. Pirsson, analyst. (MgO corrected.)

II. Montanose (shonkinite) from Bearpaw Mountains. H. N. Stokes, analyst. Weed and Pirsson, Am. Jour. Sci., 4th ser., vol. 1, 1896, p. 360 (includes Fl.=.16).

III. Shonkinose (shonkinite) from Yogo Peak, Montana. W. F. Hillebrand, analyst. Weed and Pirsson, Am. Jour. Sci., 3d series, vol. 50, 1895, p, 474.

IV. Montanose (shonkinite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst (includes S=.03; ZrO_2=.03).

V. Shonkinose (shonkinite) from Maros Peak, Borneo. Doctor Hinden, analyst. C. Schmidt in Sarasin's Celebes, vol. 4, 1901, p. 23.

VI. Shonkinose (shonkinite) from Maros Peak, Borneo. Doctor Hinden, analyst. C. Schmidt in Sarasin's Celebes, vol. 4, 1901, p. 23.

VII. Kentallenose (kentallenite) from Glen Shira, Argyllshire, Scotland. W. Pollard, analyst. Hill and Kynaston, Quart. Jour. Geol. Soc., vol. 56, 1900, p. 537.

These features are found in similar rocks from other Montana localities, as has been previously pointed out. As at Square Butte, they are also border differentiates of a single intruded mass. Its close similarity to montanose, described in a following section, is seen by comparing the analyses (I and IV of above table). The chief difference is that the montanose is considerably higher in alkalies and lower in ferromagnesian oxides. A closely related rock has recently been described by Schmidt from the island of Borneo under the name of shonkinite. It consists of augite, biotite, olivine, orthoclase, labradorite, with accessory apatite, iron ore, nephelite, and sodalite. Analyses of two specimens are given under V and VI. They closely resemble III, and the considerable amount of alkalies shows that they would fall near the subrang with the montanose, described later.[a]

In his work on the Monzoni rocks, Brögger[b] quoted an analysis of Lemburg's of a "pyroxenite" with large crystals of orthoclase, and pointed out the resemblance of these types to shonkinite. In his recent interesting study of the rocks of this region, Doelter[c] states that shonkinite occurs among them, but the type described is said to contain considerable plagioclase, which Romberg[d] calls attention to. The latter also states (p. 37) that shonkinite occurs on the Mulatto. Until more detailed studies and chemical analyses of these rocks have been made it will be impossible to form any definite opinion as to where they belong.

It is evident that while essexite, shonkinite, theralite, and alkalic pyroxenites all possess clear-cut and definite characters, there are many intermediate types whose classification in the older systems will be entirely a matter of opinion. So, for example, Hill and Kynaston have described, under the name of kentallenite, a rock consisting of essential olivine and augite with orthoclase and plagioclase in varying proportions. Its analysis is shown under VII of the table. The close chemical similarity to shonkinite is easily seen. In the new system of classification it has, however, a distinct place of its own.

Mineral composition or mode.—By study of the thin sections, with comparison of the chemical analysis and the powders yielded by the

[a] A calculation of the norm from analysis V gives the following results:

Or	38.92	57.55
An	5.28	
Ne	13.35	
Di	19.00	40.12
Ol	12.36	
Mt	3.94	
Il	2.13	
Ap	2.69	
H_2O	1.66	
Total	99.33	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{57.55}{40.12}=1.4=$III, salfemane.

Order, $\frac{L}{F}=\frac{13.35}{44.20}=.30=$lendofelic$=6$, portugare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{117}{19}=$domalkalic$=2$, monchiquase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{70}{47}=1.49=$sodipotassic$=3$, shonkinose.

[b] Triad. Erup. Predazzo, 1896, p. 67.

[c] Tschermak, Min. Mitt., vol. 21, 1902, pp. 100 and 103.

[d] Sitzb. k. Preuss. Akad. Wiss. Berlin., Phys., Mat., Kl., vols. 30, 32, 1902, pp. 675, 731.

heavy liquids, it may be calculated that an average specimen of the Square Butte shonkinose would have this mineral composition:

Mineral composition or mode of shonkinose of Square Butte.

Alkalic feldspar	20
Nephelite	5
Sodalite	1
Augite	46
Olivine	10
Biotite	8
Iron ore	6
Apatite	4
Total	100

Classification in the new system.—The calculation of the norm of the Square Butte rock and its position in the new system are shown in the following table:

Calculation of the norm of shonkinose.

	Analysis.	Molecular ratio.	Or.	Ab.	Ne.	So.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	46.73	0.779	240	18	44	6	60	338	72			
Al_2O_3	10.05*	.098	40	3	22	3	30					
Fe_2O_3	3.53	.022								22		
FeO	8.20	.114						44	38	22	10	
MgO	9.27	.232						125	107			
CaO	13.22	.236					30	169				37
Na_2O	1.81	.029		3	22	4						
K_2O	3.76	.040	40									
TiO_2	.78	.010									10	
P_2O_5	1.51	.011										11
Cl_2	.18	.003				1						2
Rest	1.52											
Total	100.56		40	3	22	1	30	169	72	22	10	11

Or	22.24	39.37
Ab	1.57	
An	8.34	
Ne	6.25	
So	.97	
Di	37.91	59.59
Ol	11.36	
Mt	5.10	
Il	1.52	
Ap	3.70	
Rest	1.52	
Total	100.48	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{39.37}{59.59}=.66=$III, salfemane near dofemane.

Order, $\frac{\text{L.}}{\text{F.}}=\frac{7.22}{32.15}=.22=$lendofelic$=6$, portugare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{69}{30}=2.3=$domalkalic$=2$, monchiquase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{40}{29}=1.4=$sodipotassic$=3$, shonkinose.

Grad, $\frac{P+O}{M}=\frac{49.27}{6.62}=7.4=$perpolic$=1$, shonkinate.

Subgrad, $\frac{(MgFe)O+CaO''}{(K\,Na)_2O''}=\frac{483}{0}=$permirlic$=1$, shonkinote.

In comparing the norm with the mode it is seen that in the norm there is about 8 per cent of anorthite, which in the mode has gone almost entirely into the augite, and, conversely, about 8 per cent of biotite in the rock resolves itself in the norm into olivine and feldspathic minerals.

This biotite is thus a varietal mineral and produces a model variety of the normative rock. The texture is granular, and the type may thus be termed biotitic grano-shonkinose.

SHONKINOSE OF OTHER HIGHWOOD LOCALITIES.

Besides the occurrence at Square Butte, this rock is found in Palisade Butte, in the smaller laccolith in the Shonkin Sag, in the great stock at the head of Shonkin Creek, and in several smaller masses and intruded sheets, as described under the discussion of the geology. There is some variation among the rocks, both in texture and in the relative proportion of minerals. The Shonkin stock varieties are apt to be coarser grained and more xenomorphic than the Square Butte type and to have much less biotite; but aside from this the types do not need any special mention and are covered by the foregoing description. One exception to this, however, is the rock closely related to shonkinose in which leucite is an essential component. This is described in the following section:

LEUCITE-SHONKINOSE (LEUCITE-SHONKINITE) OF EAST PEAK.

Introductory.—The study of the material collected by Mr. Weed at the Shonkin stock shows some variability in the proportions of the salic and femic minerals. These variations are not, however, very great and never extreme. In the hand specimens the salic and femic components appear to be similar throughout the series, but under the microscope the salic are found to be sometimes chiefly alkalic feldspars, making the rock shonkinite (shonkinose), and sometimes leucite, forming missourite (grad missourate). There are, moreover, transitional types between these two, the ferromagnesian minerals remaining the same, while the light or feldspathic ones are mixtures in various proportions of alkalic feldspars and leucite. Small amounts of nephelite, sodalite, and zeolites may also be present. In addition to these occurrences at the Shonkin stock, it has been found that the rock composing the mass of the East Peak stock at the head of Davis Creek is of this type and it was studied to ascertain its relations to the normal shonkinose.

Megascopic characters.—The occurrence and geologic relations of this rock mass have been described in a previous chapter. In the specimen the rock is a dark gray of medium to fine grain, and the automorphic character of the augites tends to give it a somewhat porphyritic appearance. In this it differs somewhat from the coarser

and massive-looking rocks of Square Butte, Shonkin Creek, etc. In addition to the augite, occasional grains of olivine are seen. The material forming the great cliff and the huge talus masses at its foot is not so fresh as the outcrops on the little ridge or foothill to the south at the border of the intrusion. The material analyzed came from this southern edge, where the rock is somewhat coarser grained.

Microscopic characters.—In thin section the rock is seen to be made up of the usual minerals of shonkinose: Augite, iron ore, apatite, olivine, biotite, with alkalic feldspars and isotropic minerals. The femic minerals are of the character already described under shonkinose. The iron ore, which is not very abundant, is in small, round, dotted grains. The augite, in large, well-formed crystals, is like that described under shonkinose. There is some olivine, which is fresh, and, unlike that in shonkinose, it is almost never surrounded by coronæ of biotite. The absence of biotite in the rock is, in fact, a noticeable feature and is to be correlated with the occurrence of leucite. This mutual relation between olivine, leucite (and its feldspar equivalent, orthoclase), and biotite is well known, and its significance in these rocks has already been shown by the writer.[a]

The alkalic feldspars are present in small laths and larger shapeless masses which often show Carlsbad twinning. In the material from the cliff and talus (Nos. 757 and 758) a curious alteration of these feldspars was noticed. When fresh they show no zonal structure, but in these cases a process of zeolitization has gone on, so that sections parallel to 010 show a marked zonal structure, alternate bands polarizing in yellow tones, while those between are the gray color usual to these feldspars in the average thin section. It appears that some zones are much richer in soda than others, and these have become converted into natrolite, which has a considerably higher birefringence than the soda orthoclase which composes the intervening layers, thus producing the effect mentioned. The alkalic feldspars are also somewhat kaolinized in some of these examples.

The leucite appears abundantly in certain areas. Between crossed nicols these areas appear homogeneous, isotropic for the most part, but here and there show the faint cross-banded twinning so characteristic of larger leucites. In plain light the areas are compound and made up of grains, as is shown by their outlines, cracks, and the zonal arrangement of fine black, dotted inclusions, a well-known feature in leucite. It is to be noted, however, that not all of the areas show these inclusions or cross twinning.

There are also some areas which in plain light show all the character of the leucite, but between crossed nicols break up into a fine mosaic of grains of low polarization. These are undoubtedly altered leucites, or pseudoleucites, consisting now of feldspar, nephelite, and zeolite granules. In the material from the cliff (757) there are no real

[a] Bull. Geol. Soc. America, vol. 6, 1895, p. 409.

leucites, but the mode of occurrence, arrangement of inclusions, etc., show that they were once present as in the rock of the south boundary (760).

Chemical composition of white components.—In order to investigate these white components a separation was made with heavy fluids and various crops obtained all the way from 2.60 to 2.25, a result which might naturally be expected in mixtures of alkalic feldspars, leucite, and zeolites. It was intended to analyze the material having a specific gravity of 2.45, the specific gravity of leucite, but unfortunately this material was lost, and the next below, at 2.38, was taken. Under the microscope this was found to be very pure, consisting of isotropic grains. About 0.2 gram was available for the analysis, which had, therefore, to be made with great care. The results were as follows:

Analysis of white component of leucite-shonkinose.

	I.	II.
SiO_2	56.00	0.933
Al_2O_3	21.27	.209
Fe_2O_3	Trace.	-------
CaO	.33	.005
Na_2O	5.16	.084
K_2O	10.85	.116
H_2O	6.89	.383
SO_3	None.	-------
Cl	None.	-------
MnO	Trace.	-------
Total	100.50	-------

By using the molecular ratios given in the last column it can be easily calculated that this material consists of a mixture of equal parts, by weight, of leucite and analcite (lc., 50.58; anc., 49.42). If the specific gravity of leucite be taken as 2.45 and that of analcite as 2.30, a mixture of equal parts of the two would have a specific gravity of 2.38, that of the powder analyzed.

Occurrence of analcite.—The presence of the analcite thus proved is of interest. It could not be detected in the ordinary way with the microscope on account of the leucite, both, of course, appearing as isotropic grains.

The question at once arises whether this analcite is primary or not. A study of the sections affords no direct evidence on this point, and the question is similar to the one raised in regard to the monchiquose (analcite-basalt), discussed elsewhere in this bulletin.

It should be noted, however, that while some of the material from this locality is considerably altered and zeolitized the specimen (760)

from the southern edge under examination shows nothing of this, and except for the presence of analcite and some pseudoleucites, or what are thought to be such, the rock is fresh and unaltered. The femic minerals are unchanged, and in the case of the olivine this is to be noted. So far as these facts afford evidence, the analcite does not appear to be due to secondary alteration. It is not logical to say that the analcite is secondary and, therefore, the rock must be altered, and that because the rock is altered the analcite must be therefore a product of alteration. The proofs of its secondary nature which are often advanced consist of just this reasoning in a circle. All that can be said in this instance is that the analcite appears like a primary mineral, and that the arguments for and against its primary nature are the same as those discussed under the head of the dikes of monchiquose (analcite-basalt). Some additional indirect evidence will be presented in a subsequent paragraph devoted to the calculation and discussion of the norm.

Chemical composition of the rock.—An analysis of this rock (760) has been made under the writer's direction by Mr. E. B. Hurlburt, with the results shown in I of the table on the opposite page.

For purposes of comparison two analyses of typical shonkinose, the original one from Square Butte and the one from Yogo Peak, are added, and it will be seen that they are all of the same general character, but that the East Peak type has higher alkalies and somewhat lower bivalent oxides. This low silica with considerable alkalies and dominant potash has caused the formation of leucite along with the alkalic feldspars. Under VIII is given the analysis of "missourite," which has no feldspar, but whose potash is all in leucite. The silica in this is the same as in the "shonkinite" of Square Butte, but the latter has lower alkalies and therefore all feldspar and no leucite. Thus, from "shonkinite" through leucite-"shonkinite" to "missourite" there is a regularly graded series from potash feldspar through potash feldspar and leucite to leucite alone, depending on the relative proportions of silica and potash. When it is recalled that orthoclase=K_2O Al_2O_3 $6SiO_2$ and leucite=K_2O Al_2O_3 $4SiO_2$, this relation is easily understood. The soda in part follows the potash into the feldspar and in part, having a lesser affinity for silica, it forms lenad (feldspathoid) minerals throughout the series, which, if conditions of formation were favorable, might be hydrated, i. e., analcite.

The most nearly related type found by the writer outside of the Highwood area is a shonkinose ("leucitophyre") from Persia, whose analysis, by Steinecke, is shown under IV. The chemical correspondence of these two rocks from such widely separated regions is remarkable; the only difference is that the Persian type contains a little less iron and a little more lime.

The correspondence between leucite-shonkinose and the nearly related montanose ("shonkinite") from the Shonkin Sag laccolith is

Analyses of leucite-shonkinose and related rocks.

	I	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	49.59	46.73	48.98	49.65	47.88	46.04	47.98	46.06	0.827
Al_2O_3	14.51	10.05	12.29	14.39	12.10	12.23	13.34	10.01	.142
Fe_2O_3	3.51	3.53	2.88	4.21	3.53	3.86	4.09	3.17	.022
FeO	5.53	8.20	5.77	3.46	4.80	4.60	4.24	5.61	.076
MgO	6.17	9.25	9.19	6.27	8.64	10.38	7.01	14.74	.154
CaO	9.04	13.22	9.65	10.12	9.35	8.97	9.32	10.55	.160
Na_2O	3.52	1.81	2.22	3.21	2.94	2.42	3.51	1.31	.056
K_2O	5.60	3.76	4.96	5.46	5.61	5.77	5.00	5.14	.060
H_2O+	1.95	1.24	.56	2.37	1.52	2.87	2.10	1.44	-----
H_2O-	-------	-------	.26	-------	.70	-------	-------	-------	-----
CO_2	-------	-------	-------	-------	.12	-------	1.24	-------	-----
TiO_2	.36	.78	1.44	(?)	.77	.64	.58	.73	.004
P_2O_5	.15	1.51	.98	.79	1.11	1.14	1.03	.21	.001
SO_3	.02	-------	-------	-------	None.	Tr.	Tr.	.05	-----
Cl	.13	.18	-------	-------	Tr.	.11	.21	.03	-----
Cr_2O_3	-------	-------	Tr.	-------	.04	-------	-------	-------	-----
Fl	-------	-------	.22	-------	.05	-------	-------	-------	-----
MnO	Tr.	.28	.08	.25	.15	Tr.	Tr.	Tr.	-----
BaO	.49	(?)	.43	(?)	.46	.48	.50	.32	.003
SrO	.21	(?)	.08	(?)	.13	.25	.14	.20	-----
	100.78	100.56	99.99	100.19	99.99	99.76	100.29	99.57	-----
O=Cl	.03	.04	.10	-------	.02	.03	.07	.01	-----
Total	100.75	100.52	99.89	100.19	99.97	99.73	100.22	99.56	-----

I. Leucite-shonkinose (leucite-shonkinite) from East Peak, Highwood Mountains, Montana. E. B. Hurlburt, analyst.

II. Shonkinose (shonkinite) from Square Butte, Highwood Mountains, Montana. L.V. Pirsson, analyst. Bull. Geol. Soc. America, vol. 6, 1895, p. 414.

III. Shonkinose (shonkinite) from Yogo Peak, Little Belt Mountains, Montana. W. F. Hillebrand, analyst. Am. Jour. Sci., 3d series, vol. 50, 1895, p. 474.

IV. Shonkinose (leucitophyre) from near Khoi, Persia. J. Steinecke, analyst. Zeit. Naturw. Halle, vol. 6, 1887, p. 12.

V. Montanose (shonkinite) from Shonkin Sag laccolith, Highwood Mountains, Montana. W. F. Hillebrand, analyst. Am. Jour. Sci., 4th series, vol. 12, 1901, p. 14.

VI. Biotite-cascadose (mica-basalt) from Arrow Peak dike, Highwood Mountains, Montana. H. W. Foote, analyst.

VII. Shonkinose (leucite-basalt) from Pinewood Peak flow, Highwood Mountains, Montana. H. W. Foote, analyst.

VIII. Albanose (missourite) from head of Shonkin Creek, Highwood Mountains, Montana. E. B. Hurlburt, analyst. Am. Jour. Sci., 4th series, vol, 2, 1896, p. 321.

IX. Molecular proportions of No. I.

shown by a comparison of the analyses I and V, respectively, which show how delicate is the balance which determines the formation of orthoclase and biotite instead of orthoclase with leucite and olivine.

Under VI and VII are analyses of dikes and flows of the region, and comparison may be made not only with the leucite-shonkinose but also of the normal shonkinose with similar magmas of the area which have a different method of occurrence.

Mineral composition or mode.—On account of the mingled analcite and leucite the mineral composition can not be accurately computed, but the relation of the salic to the femic minerals is expressed very closely in the norm, which represents also in a general way the femic minerals. If the leucite pseudomorph areas are reckoned as leucite, observation shows that the amount of leucite to feldspar is about 7 to 3; but a considerable proportion of what is called leucite—perhaps a third or more—is really analcite.

Classification in the new system.—The position of the rock in the new system is shown in the following computation of its analysis:

Calculation of the norm of leucite-shonkinose.

	Analysis.	Molecular ratio.	Or.	Lc.	Ab.	Ne.	So.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	49.59	0.826	360		6	94	12	56	260	36			
Al_2O_3	14.51	.142	60		1	47	6	28					
Fe_2O_3	3.51	.022									22		
FeO	5.53	.076							31	18	22	5	
MgO	6.17	.154							99	55			
CaO	9.04	.161						28	130				3
Na_2O	3.52	.056			1	47	8						
K_2O	5.60	.060	60										
TiO_2	.36	.005										5	
P_2O_5	.15	.001											1
Cl_2	.13	.002					2						
Rest	2.67												
Total	100.78		60		1	47	2	28	130	36	22	5	1

Or	33.36	56.94
Ab	.52	
An	7.78	
Ne	13.35	
So	1.93	
Di	29.07	40.95
Ol	5.68	
Mt	5.10	
Il	.76	
Ap	.34	
Rest	2.67	
Total	100.56	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{56.94}{40.95}=1.2=$ III, salfemane.

Order, $\frac{L}{F}=\frac{15.28}{41.66}=0.36=$ lendofelic $=6$, portugare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{116}{28}=4.1=$ domalkalic $=2$, monchiquase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{60}{56}=1.0=$ sodipotassic $=3$, shonkinose.

The calculation shows the rock to be a normal shonkinose with orthoclase and nephelite and no leucite. The reason of this is apparent when one considers that nephelite has been calculated instead of analcite. The formula of nephelite is $Na_2O\ Al_2O_3\ 2SiO_2$ and that of analcite is $Na_2O\ Al_2O_3\ 4SiO_2\ 2H_2O$. The formation of theoretical nephelite consequently releases enough silica to convert what would otherwise be leucite into orthoclase. This is a strong argument in favor of the primary nature of the analcite. If the rock had crystallized anhydrously, we should have expected the formation of the minerals shown in the norm. Considering our knowledge of the crystallization of molten magmas and the affinities of the oxides, they could not have been different from these. If the analcite is secondary, the aqueous solutions have taken silica from orthoclase, reducing it to leucite and converting nephelite into analcite. In this case the leucite is also secondary. If we reject this, we must fall back on the view that aqueous solutions carrying soda and silica have acted on the rock and presumably on leucite, have removed from a part of it a vast amount of potash and replaced it with soda, and have not attacked the other minerals, especially the olivine. The action thus becomes an entirely selective one. It would seem simpler to suppose that the water vapor originally present in the magma caused the formation of analcite, and thus indirectly also of leucite.

From what has been shown it is evident that this rock has an abnormative mode, and since it has a granular texture it should be termed a grano-leucite-shonkinose.

Classification in prevailing systems.—As the white components of this rock consist chiefly of leucite and alkalic feldspar it was at first provisionally termed leucite-syenite, under which name the analysis was first published in Bulletin 148 of the United States Geological Survey. Considering, however, the relative amounts of light and dark minerals, its chemical composition, and its regional affinities, the name leucite-shonkinite would be much more appropriate.

MONTANOSE (SHONKINITE) OF SHONKIN SAG LACCOLITH.

Introductory.—In the rocks of the stocks and laccoliths the order portugare of the salfemanes in the new system of classification is represented in both the peralkalic and the domalkalic rangs, wyomingase and monchiquase. In subrangs it is the sodipotassic in both, and under monchiquase it is shonkinose. The rocks have been fully described and their positions shown in the foregoing section.

Under wyomingase, where the rocks are peralkalic, subrang 3 has received no name, and it is here proposed to describe a Highwood type which occurs within it and call this subrang montanose. This is the material forming the dark outer zone of the Shonkin Sag laccolith.

Under prevailing systems of classification, in which regard is paid only to the presence of certain minerals and none to their relative quantities, the difference between the relative amounts of the alkalic minerals in this type and the shonkinose last described would not be recognized, and both rocks would be classed under shonkinite.

Megascopic and microscopic characters.—In the hand specimen the rock is much like the former type, a dark-gray, medium- to coarse-grained mixture of salic and femic minerals. There is less automorphism in the femic minerals than in the Square Butte rock.

In thin sections there appear the same minerals as in shonkinose—iron ore, apatite, olivine, biotite, augite, alkalic feldspars, nephelite, sodalite, and some zeolites. The apatite and iron ore are similar; the fresh olivine is in the same way surrounded by biotite mantles, brown within and green without, where contact would be made with the orthoclase. The biotite is well crystallized and tends to form in long foils and have darker borders, as in minette; it recalls the biotite of theralite, but has parallel extinction. The augite in places has fine borders of a deeper green, from admixture of the ægirite molecule. There is present some soda microcline with very fine albite twinning which is partly zeolitized. The orthoclase is like that in shonkinose. Considerable nephelite is present, shown by its uniaxial negative cross and low birefringence; it is fresh, but often incloses hexagons of zeolitized sodalite. The texture, fabric, etc., are as in shonkinose.

Chemical composition.—The chemical composition of this rock is shown in a complete analysis by Dr. W. F. Hillebrand; it has been given under shonkinose, but is repeated on the opposite page for the sake of convenience.

In Washington's[a] tables of analyses are found two other analyses which come under this subrang. One is of shonkinite of the Beaver Creek stock in the Bearpaw Mountains; the other differs in the presence of much ægirite as its dominant femic mineral, and one would naturally classify it under an entirely different grad and subgrad. It is interesting to note in connection with this analysis how ferrous iron plays the function usually filled by magnesia, while soda, in forming a femic mineral, does the same for lime.

The analysis of the Shonkin Sag montanose shows all the distinctive characters of the salfemic rocks of the Highwoods, and it is unnecessary to do more than point this out.

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[a] Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 338.

Analyses of montanose and related rocks.

	I.	II.	III.	IV.
SiO_2	47.88	50.00	48.90	0.796
Al_2O_3	12.10	9.87	7.85	.119
Fe_2O_3	3.53	3.46	11.46	.022
FeO	4.80	5.01	13.32	.067
MgO	8.64	11.92	.38	.216
CaO	9.35	8.31	1.95	.167
Na_2O	2.94	2.41	7.40	.047
K_2O	5.61	5.02	3.23	.060
H_2O+	1.52	1.16	1.80	
H_2O-	.70	.17		
CO_2	.12	.31		
TiO_2	.77	.73		.010
P_2O_5	1.11	.81		.008
SO_3	None.	.02		
Cl	Trace.	.08	.03	
Cr_2O_3	.04	.11		
NiO	Trace.	.07		
MnO	.15	Trace.	1.11	
BaO	.46	.32		
SrO	.13	.07		
Total	99.99	100.01	99.39	

I. Montanose (shonkinite) from Shonkin Sag laccolith, Highwood Mountains. W. F. Hillebrand, analyst (includes S.=.03, ZrO_2=.03, Fl.=.05, and V_2O_3=.04).

II. Montanose (shonkinite) from Beaver Creek, Bearpaw Mountains, Montana. H. N. Stokes, analyst (includes Fl.=.16). Am. Jour. Sci., 4th series, vol. 1, 1896, p. 360.

III. Montanose from Kangerdluarsuk, Greenland. C. Detlefson, analyst (includes ZrO_2=1.96). Rosenbusch, Elemente, p. 133, 1898.

IV. Molecular proportions of No. I.

Classification in the new system.—The position of the rock in the new system is shown in the following calculation of its norm and systematic position:

Calculation of the norm of montanose.

	Analysis.	Molecular ratio.	Or.	Ne.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	47.88	0.796	360	94	24	258	61			
Al_2O_3	12.10	.119	60	47	12					
Fe_2O_3	3.53	.022						22		
FeO	4.80	.067				18	17	22	10	
MgO	8.64	.216				111	105			
CaO	9.35	.167			12	129				26
Na_2O	2.94	.047		47						
K_2O	5.61	.060	60							
TiO_2	.77	.010							10	
P_2O_5	1.11	.008								8
Rest	3.26									
Total	99.99									

Or	33.36	50.05
An	3.34	
Ne	13.35	
Di	28.44	46.83
Ol	9.08	
Mt	5.10	
Il	1.52	
Ap	2.69	
Rest	3.26	
Total	100.14	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{50.05}{46.83}=1.0=$III, salfemane.

Order, $\frac{\text{L.}}{\text{F.}}=\frac{11.35}{36.70}=0.36=$lendofelic$=6$, portugare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{107}{12}=9=$peralkalic$=1$, wyomingase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{60}{47}=1.3=$sodipotassic$=3$, montanose.

Grad, $\frac{\text{P.}+\text{O.}}{\text{M.}}=\frac{37.52}{6.62}=5-2$, dopolic.

Subgrad, $\frac{(Mg\,Fe)O+CaO''}{(NaK)_2O''}=\frac{370}{0}=1$, permirlic.

In chemical composition this rock stands very near the center of th subrang, and it is therefore very nearly a typical analysis. That thi is so may be seen if we assume exact center points and then from thi reverse the ordinary process of calculation, obtaining the theoretica chemical composition and the corresponding norm for the assume rock.

Calculation of chemical composition.

I.	II.	III.	Or.	Ab.	Ne.	Di.	Ol.	Mt.
SiO_2	50.8	0.846	342	54	96	282	72	
Al_2O_3	11.6	.114	57	9	48			
Fe_2O_3	6.5	.041						41
FeO	3.0	.041						41
MgO	11.4	.285				141	144	
CaO	7.9	.141				141		
Na_2O	3.5	.057		9	48			
K_2O	5.4	.057	57					
Total	100.1		57	9	48	141	72	41

Norm.

Or	31.7
Ab	4.7
Ne	13.5
Di	30.6
Ol	10.0
Mt	9.4
Total	99.9

Center points.

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{50}{50}=1.0=$III, salfemane.

Order, $\frac{\text{L.}}{\text{F.}}=0.37=6$, lendofelic.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=00=$I, peralkalic.

Subrang, $\frac{Na_2O}{K_2O}=1.0=3$, sodipotassic.

The calculated chemical composition given in column II of the above table is seen to be, in general, very close to the actual analysis previously given.

The mode or actual mineral composition of the rock differs from this theoretical norm in that some of the molecules which would otherwise have gone to making olivine and feldspathoid minerals have actually united to make about 10 per cent of biotite. On account of this biotite and because the texture is granular the rock should be termed "biotitic grano-montanose."

MISSOUROTE (MISSOURITE) OF THE SHONKIN STOCK.

Introductory.—This rock has been described in a previous paper by the author and Mr. Weed, who collected the material and gave an account of its mode of occurrence in the Shonkin stock. As the type filled a gap in the prevailing systems of classification and was the first recorded instance, so far as known to the writer, of an intrusive rock containing unaltered leucite, it has become widely known, and the name was adopted in petrographic nomenclature. In the new classification it occupies an interesting position, as will be shown, and in order to facilitate the discussion the essence of the former description and the chemical analyses are here repeated. The locality and mode of occurrence have been given in the description of the Shonkin stock.

Megascopic characters.—The rock appears dark gray, coarse

grained, and resembles many basic massive rocks in appearance. In the specimen it is seen to be coarsely and evenly granular and to be composed of light and dark constituents, the proportion by bulk being about two of the light to three of the dark minerals. The separation by the heavy fluids shows, however, that by weight the white mineral forms only one-fifth to one-quarter of the whole. The distinction in color is strongly marked and gives the rock a mottled, mosaic-like appearance.

Upon examination the dark constituents may be distinguished as chiefly a greenish-black augite in columnar masses and aggregates which are never automorphic, and an occasional speck of a bronzy brown biotite of ill-defined outline or a grain of a deep-yellow olivine. Filling the interspaces between these dark minerals in formless masses is a very pale greenish-gray substance which is leucite. The average size of crystal grain varies from 2 to 5 mm, so that the rock is of coarse granular structure, and resembles most strikingly many coarse-grained gabbros.

Microscopic characters.—The thin section under the microscope shows the minerals present to be apatite, iron ore, olivine, augite, biotite, leucite, and some zeolitic products.

The apatite and iron ore, which are present rather rarely in moderate-sized grains, show nothing of especial interest beyond that they are found inclosed in the other minerals, and the biotite frequently incloses the iron ore.

The olivine is extremely fresh, unaltered in any way, and resembles the olivine of fresh gabbros. It contains great numbers of very fine glass and iron-ore inclusions. It never shows any crystal faces, but is in rounded, formless, anhedral grains which are frequently inclosed in biotite and augite.

The augite is of a pale-green color with a tone of brown; it is very fresh and clear, contains inclusions of ore and specks of biotite, and is entirely xenomorphic, though the orientation of the ore grains is at times zonal, thus indicating crystal planes. It has an excellent cleavage, and twinning bands pass through it in places; it does not show any pleochroism.

The biotite is strongly pleochroic between a deep umber-brown and a pale yellow-brown; it is also entirely xenomorphic, though apt to surround the other minerals in bands, especially the olivine and iron ore. It is particularly characteristic in such cases that it passes from brown into an olive-green variety which has a mottled, somewhat stringy, fibrous appearance. In these cases it appears as if the brown variety had suffered from some magmatic process; it does not seem to be due to any ordinary process of weathering.

The leucite also appears in formless masses filling the interspaces between other minerals. It is perfectly clear and free from all inclusions, except now and then a grain of the ferromagnesian minerals. Between crossed nicols it shows most beautifully the cross-banded

twinning structure so characteristic of leucite. It is in general perfectly clear, limpid, and fresh, though in some areas, in delicate fringes along cracks and on the borders of grains, a low birefraction shows that processes of zeolitization have commenced.[a]

Chemical composition.—An analysis of the rock has been made by Mr. E. B. Hurlburt, with the following results:

Analyses of missourote and related rocks.

	I.	II.	III.	IV.	Ia.
SiO_2	46.06	47.28	46.73	44.35	0.767
Al_2O_3	10.01	11.56	10.05	10.20	.097
Fe_2O_3	3.17	3.52	3.53	13.50	.020
FeO	5.61	5.71	8.20		.078
MgO	14.74	13.17	9.27	12.31	.368
CaO	10.55	9.20	13.22	11.47	.188
Na_2O	1.31	2.73	1.81	3.37	.021
K_2O	5.14	2.17	3.76	4.42	.054
H_2O	1.44	2.96	1.24	(?)	.080
TiO_2	.73	.88	.78	(?)	.009
P_2O_5	.21	.59	1.51	(?)	
MnO	Trace.	.13	.28		
BaO	.32	(?)	(?)	(?)	
SrO	.20	(?)	(?)	(?)	
SO_3	.05		None.		
Cl	.03	.18	.18		
	99.57	100.08	100.56	99.62	
Cl=O	.01	.04	.04		
Total	99.56	100.04	100.52		

I. Missourote (missourite), from head of Shonkin Creek, Highwood Mountains, Montana. E. B. Hurlburt, analyst.

II. Camptonose (leucite-absarokite). J. E. Whitfield, analyst. Hague, Am. Jour. Sci., 3d series, vol. 38, 1889, p. 43. Iddings, Jour. Geol., vol. 3, 1895, p. 938.

III. Shonkinose (shonkinite) from Square Butte, Highwood Mountains. L. V. Pirsson, analyst. Bull. Geol. Soc. America, vol. 6, 1895, p. 414. MgO corrected.

IV. Leucite-basalt, from Bongsberg, by Pelm, Eifel. E. Hussak, analyst. Sitzb. K. Akad Wiss. Wien, vol. 77, pt. 1, 1878.

Ia. Molecular ratios of No. I.

[a] An analysis of it on material separated by heavy liquids gave—

SiO_2	54.46
Al_2O_3	22.24
Fe_2O_3	.68
CaO	.10
Na_2O	.70
K_2O	18.86
H_2O	2.29
Total	99.33

This analysis brings out strongly the leading characteristics of the rock—its very high lime, iron, and magnesia, which have compelled the formation of such quantities of pyroxene and olivine, and the predominance of potash over soda, which, with the low silica, has conditioned the formation of the leucite and prevented the forming of feldspar.

Mineral composition or mode.—Taking into account the ratios shown by the analysis, the separations by the heavy liquid, and the study of the section, the rock has approximately the following mineral composition:

Mineral composition or mode of missourote.

Iron ore	5
Augite	50
Olivine	15
Biotite	6
Leucite	16
Analcite	4
Zeolites	4
Total	100

This composition as originally calculated must be approximately correct, as Prof. F. W. Clarke informs the writer that on leaching the rock with ammonium chloride the following percentages were obtained in the extract:

	A.	B.
CaO	1.73	1.70
K_2O	4.09	3.74
Na_2O	.59	.64

This gives, on calculation into mineral molecules, leucite ($K\ Al\ Si_2O_6$), 18.24; analcite ($Na\ AL\ Si_2O_6H_2O$), 4.70.

As the rock itself varies somewhat this may be considered a very satisfactory agreement.

Classification in prevailing systems.—In the prevailing systems of classification this rock has a distinct place. It is the massive granular, plutonic representative of the leucite-basalts and bears the same relation to them that gabbro bears to common plagioclase-basalt or granite to rhyolite. For this reason it was given a distinct name of its own, missourite. The writer can not agree with the suggestion by Löwinson-Lessing[a] that leucite-gabbro would have been appropriate, for in the usage of petrographers this would have meant a gabbro—that is, a plagioclase rock—with additional leucite, and this

[a] Löwinson-Lessing, Studien ueber die Eruptivgesteine: Compte-rendu vii session Cong. Geol. Inter. Russ., 1897, p. 282.

ould have been incorrect. This idea was thought of at the time and iis name in consequence rejected.

Classification in the new system.—In the new system the rock occuies an interesting position, and one which, moreover, points a moral ı regard to all systems of rock classification based on the inherent ature of the things classified. Its norm is determined from the fol›wing calculation:

Calculation of the norm of missourote.

	Analysis.	Molecular ratio.	Or.	Lc.	Ne.	An.	Di.	Ol.	Mt.	Il.	Ap.
iO_2	46.06	0.767	36	192	42	46	324	127	----	----	----
l_2O_3	10.01	.098	6	48	21	23	------	------	----	----	----
e_2O_3	3.17	.020	----	------	----	----	------	------	20	----	----
eO	5.61	.078	----	------	----	----	19	30	20	9	----
IgO	14.74	.368	----	------	----	----	143	225	----	----	----
aO	10.55	.188	----	------	----	23	162	------	----	----	3
a_2O	1.31	.021	----	------	21	----	------	------	----	----	----
$_2O$	5.14	.054	6	48	----	----	------	------	----	----	----
iO_2	.73	.009	----	------	----	----	------	------	----	9	----
$_2O_5$	.21	.001	----	------	----	----	------	------	----	----	1
Rest	2.04	--------	----	------	----	----	------	------	----	----	----
Total	99.57	--------	6	48	21	23	162	127	20	9	1

Or	3.34	36.60
An	6.39	
Lc	20.93	
Ne	5.94	
Di	35.60	60.76
Ol	18.81	
Mt	4.64	
Il	1.37	
Ap	.34	
Rest	2.04	
Total	99.40	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{36.60}{60.76}=.601=\text{III}$, salfemane.

Order, $\frac{\text{L.}}{\text{F.}}=\frac{26.87}{9.73}=2.1=$dolenic$=8$, bohemare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{75}{23}=3.2=$domalkalic$=2$, albanase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{54}{21}=2.6=$dopotassic$=2$, albanose.

Grad, $\frac{P+O}{M}=\frac{54.41}{6.01}=9=$perpolic$=1$, missourate.

Subgrad, $\frac{(MgOFeO)+CaO''}{(K\,Na)_2O''}=\frac{608}{0}=$permirlic$=1$, missourote.

The rock is almost exactly on the dividing line between salfemane and dofemane, which is $\frac{\text{Sal}}{\text{Fem}}=\frac{3}{5}=.6$. If the BaO and SrO are taken into account—their amounts are given in the analysis on a preceding page—and they are reckoned in with the feldspars, where they clearly belong, the norm figures out—

Orthoclase	1.11	36.40
Leucite	22.67	
Nephelite	5.94	
Anorthite	5.28	
Hyalophane	1.40	
Diopside	36.68	61.63
Olivine	18.60	
Magnetite	4.64	
Ilmenite	1.37	
Apatite	.34	
Rest	1.52	
Total	99.55	

Class. $\frac{\text{Sal}}{\text{Fem}}=\frac{36.40}{61.63}=.590=$ IV, dofemane.

Order. $\frac{\text{P}+\text{O}}{\text{M}}=\frac{55.28}{6.35}=8.9=$ perpolic $=1$, hungarare.

Section. $\frac{\text{P}}{\text{O}}=\frac{36.68}{18.60}=1.9=2$, dopyric.

Rang, $\frac{\text{CaO}''+\text{MgO}+\text{FeO}}{\text{Na}_2\text{O}''}=\frac{613}{0}=1$, permirlic.

Section, $\frac{\text{MgO}+\text{Feo}}{\text{CaO}''}=\frac{426}{167}=2.5=2$, domiric.

Subrang, $\frac{\text{MgO}}{\text{FeO}}=\frac{368}{78}=4.9=2$, domagnesic.

Grad, $\frac{\text{E}}{\text{F}}=\frac{28.61}{7.79}=3.8=5$, prelenic.

Subgrad, $\frac{\text{K}_2\text{O}'+\text{Na}_2\text{O}'}{\text{CaO}'}=\frac{75}{19}=3.8=1$, prealkalic.

Reckoning in the BaO and SrO, the rock just crosses the line and becomes a dofemane. These other divisions have not been named, and no name is offered for them here, since a type standing more nearly in the center of each should be chosen. It is then salfemane-dofemane, bohemare-hungarare, etc., and the double name should be carried down. Since, however, the leucite is the most interesting component, and in the salfemanes the name albanase has appropriately been given to the domalkalic rang of the dolenic order to recall the fact that in the potassic subrangs leucite will be developed and the well-known Italian rocks will fall here, the name missourate may be used for the perpolic grad and missourote for the permirlic subgrad, to perpetuate the idea of a leucite-augite-olivine rock that is already connoted with this root.

Intermediate rock types.—The fact that this rock stands exactly on the line between the two classes shows that such transitional forms must occur in any system of classification which takes account of the relative quantities of minerals. They will be more numerous the more the rocks are studied and investigated. This is inherent in the very nature of rocks in which transitions occur in all directions, and is commonly looked upon by many petrographers as a difficulty, and a system of classification is regard d with favor if it professes to do away with such difficulties. There is a disposition on the part of many to regard such rocks as not typical, to say they are less abundant or not so important as those which fall in the middle of a unit, or to regard them as varieties or facies, or anything, in fact, which will minimize their importance and make the difficulty of classifying them less. The real difficulty lies not in the rocks, but in the petrog-

raphers. These difficulties will occur as long as petrographers endeavor to classify rocks into units which shall correspond to species in other domains of natural science and to force varied types to agree with such units. The main difficulties of each classification will disappear if it is recognized that there is no natural classification of rocks, and that the subject-matter spreads itself in a broad uninterrupted field, which is arbitrarily divided into units for convenience in description and nomenclature. Rocks which lie on the border will then be assigned to their proper place, their importance will be felt to be just as great as those away from dividing lines, and their systematic position will receive due consideration.

PETROGRAPHY OF THE DIKES AND SHEETS.

INTRODUCTION.

As the intrusive sheets of the Highwoods are geologically inconspicuous when compared with the dikes, and they have no petrographic characters which distinguish them from the dikes in such a degree that they deserve separate mention, the dikes and sheets are treated together in this description of their petrography.

In the field these rocks divide themselves roughly into light and dark types; in the language of the new classification, into salic and femic types. The persalanes, dosalanes, and salfemanes are represented, but no types more femic than these occur. Thus they represent the rocks found in the stocks and laccoliths in granular types. On the other hand, they are not much more differentiated than those, and the differences are chiefly textural ones, due to different physical conditions in cooling and crystallizing. These facts, merely alluded to here, will be discussed in their bearings in the chapter dealing with the petrology of the Highwood region.

In tabulated form the following types of rocks are found in the dikes and sheets, the names in both the old and the new classification being given for convenience:

Pulaskose or sölvsbergite-porphyry.
Highwoodose or tinguaite of Highwood type.
Monzonose or gauteite (monzonitic bostonite).
Borolanose or syenite-porphyry.
Cascadose or minette of Highwood type.
Monchiquose or analcite-basalt (monchiquite).
Monchiquose or leucite-basalt (leucite-monchiquite).

TRACHIPHYRO-PULASKOSE (SODALITE-SÖLVSBERGITE-PORPHYRY).

Introductory.—A rock of tinguoid habit is found on the divide between Middle and South peaks. It occurs in a narrow dike, but a few feet wide, which is one of the series cut off by the large intrusion of the Middle Peak stock whose contact edge runs along the divide.

Megascopic characters.—In the center of the dike the rock is a medium gray with almost no tone of green. The phenocrysts of feldspar are not strongly contrasted in shape and hue with the groundmass, as in some of the other feldspathic dikes, but are more or less formless and resemble it in color; they are tabular and attain a breadth of 10 mm. Occasional tiny specks of a black, pitchy mineral are seen. Near the contact the rock becomes much denser, the groundmass is a clear dark green, and the contrast with the phenocrysts is pronounced.

Microscopic characters.—In thin section the rock displays the usual characters of a tinguoid porphyry—phenocrysts of orthoclase and ægirite, with interior cores of ægirite-augite, rather thickly scattered in a groundmass of ægirite needles and microlites of alkali-feldspar arranged in marked trachytic texture. An occasional ore grain of apatite completes the list of the usual minerals. In addition there is found dark umber-brown melanite-garnet in well-defined dodecahedrons. It occurs in rather sparsely distributed, pitchy-looking specks on the rock surface, which may be seen with the naked eye. Its total amount is small. Melanite is not an uncommon constituent in this group of rocks, being mentioned in a number of occurrences. It has been found also in tinguaite (judithose) from the neighboring Judith Mountains.[a]

Another not very common feature of tinguoid rocks is the presence of considerable sodalite. It is seen in rather well-crystallized dodecahedrons, but in the coarse-grained rock at the center of the dike it is altered to zeolites, apparently natrolite. In the dense border facies it is clear, unaltered, and isotropic. That it is sodalite and not some other isotropic mineral is indicated by absence of sulphates, ready gelatinization, and strong reaction for chlorine.

The trachytic groundmass has in spots a flamed patchy appearance, which indicates the formation of zeolites, an assumption rendered probable by the water shown in the analysis. It is possible that it formerly contained some nephelite as a cement, or that some is still present, but this can not now be proved. The smaller microlites of ægirite in it are usually decomposed to earthy material, retaining the same columnar form.

Chemical composition.—The chemical analysis of this type is shown in I of the following table. It will be seen on comparison that it is much like other tinguaites, but shows a great preponderance of potash over soda, like the other rocks of this part of Montana.

[a] Weed and Pirsson, Geology of the Judith Mountains: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 571.

Analyses of tinguoid rocks.

	I.	II.	III.	IV.	V.
SiO_2	57.18	57.63	58.90	55.65	0.953
Al_2O_3	18.54	17.53	17.70	20.06	.181
Fe_2O_3	3.65	3.46	3.94	3.45	.023
FeO	1.15	1.18	2.37	1.25	.016
MgO	.69	.22	.54	.78	.017
CaO	2.31	1.35	1.05	1.45	.041
Na_2O	4.48	5.80	7.37	8.99	.073
K_2O	8.58	9.16	5.59	6.07	.091
H_2O	2.10	3.22	1.90	1.51	
TiO_2	.30	.33	.40	Trace.	.004
MnO	Trace.	Trace.	.55		
BaO	.49	Not det.	?		
SrO	Trace.	Not det.	?		
P_2O_5	.05	Trace.	Trace.		
SO_3	.06				
Cl	.77	.08			.022
	100.35	99.86	100.33	99.21	
O=Cl	.17	.03			
Total	100.18	99.83			

I. Tinguoid trachiphyro-pulaskose, from dike on ridge between Middle and South peaks. H. W. Foote, analyst.

II. Judithose (tinguaite-porphyry), from dike on Cone Butte, Judith Mountains, Montana. L. V. Pirsson, analyst. Weed and Pirsson, Geol. Judith Mountains, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 569.

III. Umptekose (sölvsbergite-tinguaite) dike, on railroad between Tjose and Åklungen. V. Schmelck, analyst. Brögger, Grorudit-Tinguait-Serie, 1894, p. 102.

IV. Laurdalose (tinguaite) dike at Asbjörnsröd, Hedrum, South Norway. V. Schmelck, analyst. Brögger, Ganggefolge des Laurdalits, 1898, p. 377.

V. Molecular proportions of I.

Classification in the new system.—From the analysis just given it is easy to calculate the norm and the position of the rock in the new system. Without giving all the details of this in tabulated form, the results are shown in I of the table on the next page. The combination of high SiO_2 and the considerable amount of chlorine produces free quartz and sodalite.

The amount of chlorine in any case appears excessive and thus produces this anomaly. It is a good example of how carefully the small amount of chlorine in such rocks must be determined if it is to be used as a factor in determining the amount of sodalite present, and the same is true of SO_3 and nosean. Since no quartz is present in the

Calculation of the norms of tinguoid rocks.

	I.	II.	III.	IV.
Or	50.60	50.69	54.49	54.62
Ab	15.20	25.15	14.15	18.80
An	7.78	6.67		
Ne			12.50	8.81
So	10.65	5.81	.99	1.18
Qz	4.86			
Di	2.81	3.67	3.42	5.33
Ac			8.78	7.51
Hy	.40			
Wo			.93	
Mt	2.78	2.78	.70	
Il	.61	.61	.61	
Ht	1.76	1.76		
Rest	2.59	2.59	3.22	3.45
Total	100.04	99.64	99.79	99.70

I. Norm of pulaskose calculated from analysis.
II. Norm of pulaskose calculated with corrected chlorine.
III. Norm of judithose of Cone Butte.
IV. Mode of judithose of Cone Butte.

rock, we may distribute this silica so that it will raise a corresponding amount of sodalite to albite and diminish the chlorine accordingly. This gives 0.42 per cent of chlorine and the norm becomes that shown in II of the above table. The classification then becomes—

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{88.23}{8.82}=10$, $=$I, persalane.

Order, $\frac{L}{F}=\frac{5.81}{82.42}=0.05$=perfelic=5, canadare.

Rang. $\frac{Na_2O'+K_2O'}{CaO'}=\frac{164}{24}=6.8$=domalkalic=2, pulaskase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{91}{73}=1.2$=sodipotassic=3, pulaskose.

It may be remarked that No. I above would lead to the same result, since $\frac{Q}{F}$ or $\frac{L}{F}<\frac{1}{7}$ whichever be selected.

Since the study of the rock shows it to be porphyry of trachytic texture with feldspar phenocrysts, it may be designated trachisalphyro-pulaskose with tinguoid habit, or, more shortly, trachiphyro-pulaskose. This is a very condensed expression for a rock consisting chiefly of alkali feldspars, with ferromagnesian minerals less than 12.5 per cent, a small amount of anorthite feldspar in which soda and potash are molecularly about equal, and a porphyritic texture, with feldspar phenocrysts and a trachytic groundmass.

In this connection it is of interest to compare this rock with one of similar tinguoid habit from Cone Butte, in the Judith Mountains, previously described by the author. Its analysis is given in the table of analyses on page 123. It will be seen that it is similar in chemical composition, but contains less lime and higher alkalies. As a result of this it does not contain any anorthite, but a considerable amount of ægirite, and the larger proportion of femic minerals carries it into the dosalic class. This is shown on calculating its norm, which is given in III of the preceding table. Its actual mineral composition, or *mode*, is given in IV of the preceding table, and this is so close to the norm that the rock has very nearly a *normative mode*. From the norm and the analysis we may classify it as follows:

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{82.13}{14.44}=5.6=$II, dosalane.

Order, $\frac{L}{F}=\frac{13.49}{68.64}=.18=$lendofelic$=6$, norgare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{173}{0}=$peralkalic$=1$, laurdalase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{98}{75}=1.3=$sodipotassic$=3$, judithose.

The rock occupies a definite position in the subrangs, and for this reason the name of the occurrence has been given to it.

Mineral composition or mode.—The actual mineral composition, or *mode*, of the dike rock under description can not be determined with any great accuracy either from the analysis or from a study of its section. Combining both of these means of observation, it is reckoned that the mineral composition of the rock is approximately as follows:

Mineral composition or mode of trachiphyro-pulaskose.

Iron ore	2.0
Ægirite-augite	10.0
Orthoclase	50.0
Albite	10.0
Anorthite	3.0
Sodalite	10.0
Kaolin	7.0
Rest	8.0
Total	100.0

In this the full amount of chlorine given by the analysis is used to indicate the amount of sodalite, but it is thought that this is somewhat too high, and the amount shown in the norm is believed to be more nearly correct. The proportion of minerals is not strikingly different from that shown in the norm, and the rock, exception being made of the products of alteration, has in all probability a *normative mode*.

Classification in prevailing systems.—It is clear from the descriptions and analysis that in the prevailing systems of classification the

rock is closely related to the sölvsbergites, the amount of feldspathoid being relatively small for the true tinguaites. It thus lies between the sölvsbergites and the tinguaites, and differs from the normal type in that nephelite is wholly or almost wholly replaced by sodalite. It is, therefore, a novel type and might be called a sodalite-potash-sölvsbergite-porphyry. This would without doubt have a very attractive sound to timid souls who fear the introduction of new names.

TRACHIPHYRO-HIGHWOODOSE (HIGHWOOD TINGUAITE-PORPHYRY).

Introductory.—The rock of the large gray dike which forms a conspicuous wall on the east side of the upper valley of Highwood Creek, a mile or so below the divide at Highwood, is about 12 feet wide and has broken through the dark, chocolate-colored breccias. In mass it has a somewhat platy structure, and it breaks in a splintery manner under the hammer. The rock has been previously described very briefly by Lindgren,[a] under the designation trachyte, type (*b*), as feldspathic porphyritic with phenocrysts of augite, biotite, and sanidine in a groundmass of the same minerals with opacite and some glass. He mentions especially the augite, which he considers to be the same throughout all of the Highwood rocks.

Megascopic characters.—On a surface of fresh fracture the rock is a medium greenish gray. This color is produced by great quantities of small dull-white phenocrysts very thickly sprinkled in a green gray groundmass of felsitic character. In size these phenocrysts run from 1 to 2 mm. in diameter, and have a more or less pronounced square outline. In addition there are a few dark specks of a ferromagnesian mineral scattered here and there, and occasionally one of these shows the glittering cleavage of a biotite. Examination with the lens only magnifies these features; it does not bring out anything in addition.

Microscopic characters.—In thin section there are seen to be present the following minerals in a compact groundmass: Iron ore, apatite, pyroxene, biotite, and orthoclase. Iron ore is found only as rare, small grains. Apatite is seen in occasional short, stout crystals. Biotite is also rather infrequent and occurs in small, somewhat rounded tablets, which are strongly pleochroic and have dark leather-brown and pale-yellow tones.

The pyroxene ranges in size from stout columnar crystals, 2–3 mm. long, down to scarcely perceptible needles. Usually they are well crystallized and bounded by the planes (100), (110), (010), and (111), in many cases (100) being largely developed. In color they are a clear pale green, which increases in depth from center to outside. In the largest crystals the center is almost colorless, and, in general, the smaller they are the deeper is the green color they exhibit. In the latter

[a] Tenth Census U. S., vol. 15, p. 726, section c.

case, also, they possess a faint but distinct pleochroism. The angle of extinction of $c \wedge \mathfrak{c}$ is large, being 45° or over. The double refraction has an index of 0.040 proximate, which is above that of pure diopside. All these characters show that the pyroxene is a diopside enriched to some extent with the ægirite molecule; it stands between diopside and an ægirite-augite.

The feldspar phenocrysts are considerably altered to kaolin in the hand specimens gathered, only interior cores being still fresh and clear. Gooch's[a] determination of the alkalies in them shows them to be of orthoclase (K_2O 11.36, Na_2O 2.14 per cent). They occur in Carlsbad twins and in intergrown groups. They do not have good crystal outlines and with high powers show in the clear portions no signs of any micro-intergrowths with the albite molecule.

The groundmass is of the usual type found in rocks of tinguoid habit. It consists of an interlaced mass of orthoclase laths woven through with a fine felt of ægirite needles, dotted here and there with small ore grains. Biotite, which could be referred to the groundmass, was not seen, all the crystals noted being distinctly in the class of phenocrysts. This groundmass is somewhat altered, as shown by the turbid, clouded appearance given it by the kaolin granules, making its study with high power difficult. There is also more or less of an isotropic substance present. The character of the rock and its geologic occurrence practically preclude its being a glass; moreover, the rock on treatment with dilute acid gelatinizes readily, and this again is impossible for an alkali-alumina glass. The solution yields the merest trace of chlorine, which excludes sodalite, and its ready gelatinization shows that the rock can not be wholly, at any rate, made up of leucite. All this points toward analcite, and the abundant water shown in the analysis renders this still more probable. Analcite is known to occur in the base of rocks of the tinguoid group, and recently Washington[b] has described one from the vicinity of Salem, Mass., which consists chiefly of this mineral in the groundmass and which he is inclined to view as being primary in origin. Coleman[c] also has described a tinguaite-like rock, under the name "heronite," whose base consists mostly of analcite which is regarded as primary. In the present case the amount of analcite is small compared with the other minerals, and there is nothing to show whether it was original or not. The rock is not perfectly fresh; but, on the other hand, that it is somewhat altered is no proof that the analcite is secondary, since it is known that in all probability it may occur as a primary component. With the means at command at the present time there is no way of telling in this instance whether it is primary or not.

Chemical composition.—The chemical analysis of this type is shown in column I of the table on the next page.

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[a] Tenth Census U. S., vol. 15, p. 726, sec. c.
[b] Am. Jour. Sci., 4th series, vol. 6, 1898, p. 182.
[c] Jour. Geol., vol. 7, 1899, p. 431.

Analyses of highwoodose and related tinguoid rocks.

	I.	II.	III	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	58.04	57.18	57.46	57.63	58.70	58.90	62.70	55.65	0.967	0.953
Al_2O_3	17.25	18.54	15.40	17.53	19.26	17.70	16.40	20.06	.167	.180
Fe_2O_3	2.49	3.65	4.87	3.46	3.37	3.94	3.34	3.45	.015	.023
FeO	1.24	1.15	.87	1.18	.58	2.37	2.35	1.25	.017	.016
MgO	1.79	.69	1.37	.22	.76	.54	.79	.78	.045	.017
CaO	3.50	2.31	2.59	1.35	1.41	1.05	.95	1.45	.062	.041
Na_2O	3.37	4.48	5.48	5.80	8.55	7.37	7.13	8.99	.054	.072
K_2O	10.06	8.58	9.44	9.16	4.53	5.59	5.25	6.07	.107	.090
H_2O	} 1.95	2.10	.82	} 3.22	2.57	} 1.90	.70	1.51	.107	.116
H_2O-			.09		.07					
CO_2			.13							
TiO_2	.30	.30	.60	.33	Tr.	.40	.92	Tr.		
P_2O_5	.22	.05	.21	Tr.	.10	Tr.				
SO_3	Tr.	.06	.13							
Cl	Tr.	.77	.20	.08	(?)					
F			Tr.							
MnO	Tr.	Tr.	Tr.	Tr.	.10	.55				
BaO	([a])	.49	.60	([a])						
SrO	([a])	Tr.	.16	([a])						
Li_2O	Tr.	Tr.	Tr.	Tr.						
	100.21	100.35	100.42	99.86	100.00	100.33	100.53	99.21		
O=Cl		.17	.05	.03						
Total		100.18	100.37	99.83						

[a] Not determined.

I. Highwoodose (tinguaite-porphyry) from dike near head of Highwood Creek (No. 724). E. B. Hurlburt, analyst.
II. Pulaskose (tinguaite-porphyry) from dike cutting rim rock of Middle Peak stock, ridge between Middle and South peaks (No. 746). H. W. Foote, analyst.
III. Judithose (Tinguaite-porphyry) from dike at head of Bear Creek, Bearpaw Mountains, Montana. H. N. Stokes, analyst. Weed and Pirsson, Bearpaw Mountains of Montana, Am. Jour. Sci., 4th series, vol. 2, 1896, p. 192.
IV. Judithose (tinguaite-porphyry) from dike at Cone Butte, Judith Mountains, Montana. L. V. Pirsson, analyst. Weed and Pirsson. Geology of Judith Mountains, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 569.
V. Miaskose (sölvsbergite) from intrusive sheet north of Shields River, Crazy Mountains, Montana. W. H. Melville, analyst. Wolff and Tarr, Acmite-trachyte from the Crazy Mountains, Bull. Mus. Comp. Zool., Cambridge, Mass., vol. 16, No. 12, 1893, p. 232.
VI. Umptekose (sölvsbergite-tinguaite) from dike on railroad between Tjose and Aklungen, 175 kilometers from Christania, Norway. V. Schmelck, analyst. Brögger, Grorudit-Tinguait-Serie, 1894, p. 102.
VII. Umptekose (hornblende-sölvsbergite) from Lougenthal, South Norway. L. Schmelck, analyst. Brögger, loc. cit., p. 80.
VIII. Laurdalose (tinguaite) dike at Asbjörnsröd, Hedrum, South Norway. V. Schmelck, analyst. Brögger, Ganggefolge des Laurdalits, 1898, p. 377.
IX. Molecular proportions of I.
X. Molecular proportions of II.

The notable features as compared with most rocks of pronounced tinguoid habit are the extraordinarily high potash in contrast with the soda and the high lime and magnesia. It is approached in this latter respect by the tinguaite from the Bearpaw Mountains. It will be seen by glancing at the column of molecular ratios (IX) that the lime is just sufficient to turn all the ferrous iron and magnesia into pyroxene. The considerable amount of water is to be attributed in part to the analcite and in part also to the kaolin. In this analysis as originally published[a] the amount of chlorine, 0.38 per cent, is undoubtedly too high. This would indicate somewhat less than 5 per cent of sodalite, or an amount somewhat smaller than that of chlor-apatite. Several very carefully conducted tests have failed to show more than a mere trace, which is undoubtedly from the small amount of apatite present.

Mineral composition or mode.—The mineral composition can not be accurately computed from the analysis on account of several uncertainties and because each oxide is or may be present in two or more components. The analysis affords, however, a certain amount of data, and from it and a study of the section it can be rather closely reckoned that the rock consists of 20 per cent augite, including 2 or 3 per cent of iron ore, apatite, etc., and 80 per cent feldspar and feldspathoids. Of the augite, about one-third to one-quarter is ægirite and there is about 10 to 15 per cent of analcite.

Classification in prevailing systems.—When one compares the analysis of this rock with that of typical tinguaites and sölvsbergites, it is seen to differ from them, as before mentioned, in potash, magnesia, and lime; and this is expressed in the minerals, since we have diopside and ægirite-augite instead of ægirite, orthoclase instead of soda orthoclase or albite, and analcite in place of nephelite. It is to be noted also that in silica and alumina it stands between a typical tinguaite and sölvsbergite, as may be seen by reference to analyses VII and VIII. The iron is lower than in most rocks of this group. The rather small amount of feldspathoid present evidently places the rock between the sölvsbergites and the tinguaites. All these facts show that, while by its structure and general composition it belongs in this group, it is evidently a distinct variety and may be called the *Highwood* type of tinguaite.

Classification in the new system.—In the new system of classification the rock occupies a definite position by itself among the subrangs, thus filling a position otherwise vacant, and for this reason the name of highwoodose has been given it, by which the dopotassic subrang of the peralkalic rang of the perfelic order of dosalane has been designated. This is shown in the following table of calculation of the norm.

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[a] Bull. U. S. Geol. Survey No. 148, p. 152, Analysis B.

Calculation of the norm of highwoodose.

	Analysis.	Molecular ratio.	Or.	Ab.	Ne.	An.	So.	Di.	Wo.	Mt.	Il.	Ap.	Ht.
SiO_2	58.04	0.967	642	168	12	22	30	90	3				
Al_2O_3	17.25	.167	107	28	6	11	15						
Fe_2O_3	2.49	.015								13			2
FeO	1.24	.017								13	4		
MgO	1.79	.045						45					
CaO	3.50	.062				11		45	3			3	
Na_2O	3.37	.054		28	6		20						
K_2O	10.06	.107	107										
TiO_2	.30	.004									4		
P_2O_5	.22	.001										1	
Cl_2	.38	.005					5						
Rest	1.95												
Total	100.59		107	28	6	11	5	45	3	13	4	1	2

Or	59.49	83.77
Ab	14.67	
An	3.06	
Ne	1.70	
So	4.85	
Di	9.72	14.36
Wo	.35	
Mt	3.02	
Il	.61	
Ht	.32	
Ap	.34	
Rest	1.95	
Total	100.08	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{83.77}{14.36}=5.8$ = dosalic = dosalane.

Order, $\frac{L}{F}=\frac{6.55}{77.22}=0.08$ = perfelic = germanare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{161}{11}=14.6$ = peralkalic = umptekase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{107}{54}=1.99$ = dopotassic = highwoodose.

If we consider that the rock has evident phenocrysts of feldspar and a microtrachytic groundmass, it may be characterized as trachisalphyro-highwoodose with tinguoid habit. The accordance between the norm and the mode is not complete, since analcite is developed at the expense of albite, and the ægirite of the mode shows itself in iron compounds in the norm; but on the whole these constitute a modal variety rather than a real abnormative mode.

ROCKS OF TINGUOID HABIT (GRORUDITE-TINGUAITE SERIES).

This group of rocks was first given a distinct and coherent form by Brögger[a] in a monograph which has become one of the classics of petrographic literature.

The series as described by him is a group of feldspathic rocks of dense to porphyritic character occurring in narrow dikes and sheets and composed chiefly of alkali feldspars and ægirite. According to the amount of silica present there will be free quartz (grorudite),

[a] Grorudit-Tinguait-Serie, 1894.

little or no quartz (sölvsbergite), or rocks containing nephelite (tinguaite) as a result of the deficiency of silica producing this molecule instead of albite. Rosenbusch [a] calls the series "rocks of tinguaitic habit" and refers to their green color and compact grain, which are indeed useful characters for megascopic determination.

Rocks of this series have been abundantly found in central Montana in the detached outlying mountain groups, and have been described by Mr. Weed and the author from the Bearpaw, Judith, and Little Rocky mountains, and by Wolff [b] from the Crazy Mountains, under the name of acmite-trachyte. In these places they occur as narrow dikes and sheets, more rarely as marginal facies of large laccolithic masses of syenitic rocks (Little Rocky and Judith Mountains).

As appears to be generally the case in these occurrences, the rocks are satellites, dependent on rock complexes of alkalic habit and character.

Thus in central Montana they are potash tinguaites, etc., evincing therefore the regional characteristic of this well-defined petrographic province—alkalic magmas with very high potash.

In the Highwood Mountains two occurrences of rocks having this habit have just been described, both in dikes, and it is of interest to note that while the Highwood group clearly belongs to the general central Montana province, yet the rocks composing it show throughout certain local peculiarities which determine them as belonging to one clan, and the tinguoid members have certain characteristics which stamp them as forming a subgroup of the series—the Highwood group—since they wear, so to speak, the Highwood tartan.

The new system of classification is traversed in various directions by serial rock groups, according as one or more elements vary and there is a greater or lesser amount of a given mineral or minerals in the rock. The same is, of course, true in all systems of classification. Thus in the new system the rocks of tinguoid habit will be found chiefly in the persalanes and dosalanes, and in the quardofelic, perfelic, lendofelic, and lenfelic orders in each class. In the rangs they occur in the peralkalic and domalkalic, and in subrangs chiefly in the dopotassic, sodipotassic, and dosodic. This would give in theory about 48 subrangs in which this habit might be developed. However, on inspection of well-known types occurring in these subrangs, it becomes evident that the habit is rare or little known in the domalkalic dosalanes, and the number mentioned above will be reduced to about 25 or 30. Moreover, the great mass of them will be found clustering in the subrangs rich in soda, in the alkalic rangs in quardofelic, perfelic, and lendofelic orders.

[a] Elemente der Gesteinslehre, 1898, p. 211.

[b] Bull. Mus. Comp. Zool., Cambridge, Mass., vol. 16, No. 12, 1893, p. 232.

TRACHIPHYRO-MONZONOSE (GAUTEITE VARIETY OF BOSTONITE).

Occurrence.—In a small number of localities occur dikes and sheets of fine-grained, light-colored feldspathic rocks of more or less pronounced trachytic character. They are usually badly altered and weathered, so much so that in some instances they are merely crumbly masses of soil whose form, position, and more resistant contact zones on the sides alone enable them to be distinguished as dikes. On digging into such masses pieces of less altered rock may be found which enable one to recognize the type. In a very few instances they are well preserved and afford fresh material for study, as in the basin at the head of Aspen Creek, where two dikes on spurs on the north side of the main creek, west of the breccia hills, cut Cretaceous sediments. They are a mile or so apart, and, like the Highwood minette (shonkinose) dikes, they extend in the direction of the Shonkin stock. The eastern one is the larger, and is about 15 feet wide.

Megascopic characters.—In the hand specimen the rock is a pale brown, rather fine grained, and compact, but it has a markedly rough trachytic feel and appearance. This surface is rather thickly sprinkled with hornblende prisms, which are black and glittering on a cleavage face. The prisms are 10–20 mm. in length and 1–2 mm. broad. In some cases they are altered and brown or rusty. With the lens one sees also small, clear apatites; they are not common, but a considerable number may be found. The crystals are of unusual size for a rock of this character.

Microscopic characters.—Under the microscope the hornblendes are found to be of an olive-green and yellow pleochroic variety, allied to arfvedsonite and similar to the green hornblendes described in the border type of the rock of the Middle Peak stock (borolanose) and the green variety of the syenite of Square Butte (pulakose). The large apatites are well crystallized, with prisms and the common pyramid and base. They are colorless and without notable inclusions. A considerable amount of iron ore in small scattered grains is also present.

The groundmass in which these minerals lie is composed of lath-shaped feldspars, which at times tend to assume a somewhat tabular form. Careful study with high powers shows that they are sometimes untwinned, sometimes singly twinned according to the Carlsbad law, and sometimes are albite twins. Whether twinned or not, all sections whose form, edges, etc., show that they are cut in the zone perpendicular to 0.010 extinguish parallel with the nicol, and these facts in connection with the analysis prove that both alkalic and plagioclase feldspars are present and that the latter is an oligoclase. Undoubtedly the orthoclase contains considerable soda.

The chlorine and sulphur trioxide shown in the analysis would seem to indicate that considerable sodalite and nosean may be present. They are, however, not seen in the sections. A minute quantity of colorless isotropic substance is found in spots between the feldspars; this may be sodalite, but it may also be analcite, as indicated by the water. A little interstitial nephelite might also be present and escape detection. It is rather inferred that the chlorine and sulphur shown are somewhat too high, and that the chlorine comes for the greater part from the apatite, while a little pyrite might easily furnish the sulphur. It should be remembered that very small errors in the estimation of chlorine and sulphur within the limits of good analytical work will cause large variations in the amounts of sodalite and nosean estimated from them.[a]

This groundmass is somewhat stained by yellowish ferruginous material, which under the microscope is seen only in spots. There may be some zeolitization, as indicated by the water shown in the analysis.

Mineral composition or mode.—As nearly as this can be approximated, the rock contains about 5 per cent of iron ore, about 1.5 per cent of apatite, about 10 per cent of hornblende, and the rest is made up of about equal proportions of oligoclase and orthoclase feldspars.

Chemical composition.—An analysis of the large Aspen Creek dike, the eastern one of the two shown on the map, has been made by Doctor Foote, with the results shown in I of the table on the next page.

The moderate silica, high alumina, and alkalies show that this is essentially a trachytic rock, but the amount of lime, iron, and magnesia is too high for a typical rock of the class. The chlorine and sulphur have already been commented upon.

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[a] This has accordingly been taken into account in the calculation of the norm.

Analyses of monzonose (gauteite) and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	55.23	54.15	55.52	57.29	58.18	56.75	0.920
Al_2O_3	18.31	18.25	20.05	18.45	18.46	18.37	.179
Fe_2O_3	4.90	3.62	2.52	4.38	2.31	2.22	.031
FeO	2.06	2.09	2.40	1.20	3.79	3.04	.029
MgO	1.85	2.56	2.10	2.08	1.99	2.02	.046
CaO	3.62	4.89	3.15	3.57	3.11	4.68	.064
Na_2O	4.02	4.43	3.44	4.43	3.70	4.85	.065
K_2O	6.43	6.56	7.49	5.43	6.58	5.92	.068
H_2O+	1.84	3.69	1.42	2.01	.64	.18	------
H_2O-	--------	--------	--------	.17	--------	--------	------
TiO_2	.42	Trace.	.70	.72	.68	1.24	.005
P_2O_5	.58	.41	.51	.46	.41	--------	.004
SO_3	.23	--------	--------	--------	--------	--------	------
Cl	.32	--------	Trace.	--------	--------	--------	------
NiO	--------	--------	--------	.12	--------	--------	------
MnO	Trace.	--------	--------	Trace.	--------	Trace.	------
BaO	.46	--------	--------	(?)	.29	--------	------
SrO	Trace.	--------	--------	(?)	(?)	--------	------
	100.27	--------	--------	--------	--------	--------	------
Cl=O	.08	--------	--------	--------	--------	--------	------
Total	100.19	100.65	99.30	100.31	100.14	99.38	------

I. Monzonose (gauteite) from Aspen Creek, Highwood Mountains. H. W. Foote, analyst.

II. Monzonose (gauteite) from Mühlörzen, Blatt Bensen, Bohemia. R. Pfohl, analyst.

III. Monzonose (gauteite) from Gentungan, Maros Peak, Borneo. Doctor Hinden, analyst.

IV. Monzonose (quartz-banakite) from Stinkingwater River, Yellowstone Park. W. H. Melville, analyst. Iddings, Jour. Geol., vol. 3, 1895, p. 947.

V. Monzonose (odinite) from Tito, Coquimbo, Chile. A. Lindner, analyst. F. v. Wolff, Zeit. Deutsch. Geol. Gesell., vol. 51, 1899, p. 531.

VI. Monzonose (ciminite) from L'Arso, Ischia, Italy. H. S. Washington, analyst. Am. Jour. Sci., 4th ser., vol. 8, 1899, p. 290.

VII. Molecular ratios of I.

Classification in prevailing systems.—A rock of this character, containing so much plagioclase and orthoclase, and of porphyritic texture, would lie between the andesites and trachytes, and would be classed as a trachyandesite. An analysis of a rock of this character is shown in VI. Under the heading of trachyandesitic dike rocks, following the system of Rosenbusch, a few years ago Hibsch[a] described bostonoid types from the region covered by the Bensen sheet of the Bohemian Mittelgebirge survey, which differed from true bostonites in containing considerable plagioclase. He expressly notes that on account of the nearly equal mixture of orthoclase and plagioclase they should be viewed as belonging to the monzonite family of Brögger, under which they represent the bostonites of the syenitic family. Having thus a distinct place of their own, he proposed for them the name gauteite, from the hamlet of Gaute, near which a group of these dikes occur. In mineral development they are similar to the type just described, with hornblendes and the trachytic groundmass, but have in addition some augite, biotite, and numerous plagioclase phenocrysts. Having thus a more pronounced porphyritic habit, they are less like typical bostonites than the Aspen Creek rocks. These themselves vary from a typical bostonoid habit in the fact that they carry a considerable number of phenocrysts of hornblende, the original types of bostonites consisting of a trachytic groundmass alone. Chemically the close correspondence between the gauteite of Aspen Creek and the original type of Hibsch is seen by comparing the analyses given in the table.

A somewhat similar rock from the Maros Peak complex in Celebes is also described as a gauteite by Schmidt.[b] Chemically it is closely related, as may be seen by comparing its analysis. In mineral development the groundmass is purely orthoclase with some sodalite, in which lie phenocrysts of labradorite and biotite. It has been found only as an erratic, and its dike nature is surmised. At present, therefore, it can only be provisionally placed with the gauteites.

Classification in the new system.—In this the type of the rock and the relations of orthoclase and plagioclase are shown by its falling into monzonase, where it properly belongs. This is seen in the following table.

[a] Erläut. zur geol. Karte des Böhm Mittelgeb., Blatt Bensen, Tschermaks Min. Mitt., vol. 17, p. 84

[b] Sarasin's Celebes, vol. 4, 1901, appendix, p. 19.

Calculation of the norm of monzonose.

	Analysis.	Molecular ratio.	Or.	Ab.	Ne.	An.	Di.	Hy.	Mt.	Il.	Ht.	Ap.
SiO_2	55.23	0.920	408	360	10	92	10	41				
Al_2O_3	18.31	.179	68	60	5	46						
Fe_2O_3	4.90	.031							24		7	
FeO	2.06	.029							24	5		
MgO	1.85	.046					5	41				
CaO	3.62	.064				46	5					13
Na_2O	4.02	.065		60	5							
K_2O	6.43	.068	68									
TiO_2	.42	.005								5		
P_2O_5	.58	.004										4
Cl_2	.07	.001										1
Rest	2.53											
Total	100.02		68	60	5	46	5	41	24	5	7	4

Or	37.81	83.46
Ab	31.44	
An	12.79	
Ne	1.42	
Di	1.08	13.97
Hy	4.10	
Mt	5.57	
Il	.76	
Ht	1.12	
Ap	1.34	
Rest	2.53	
Total	99.96	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{83.46}{13.97}=5.9$ = II, dosalane.

Order, $\frac{L}{F}=\frac{1.42}{82.04}=.017$ = perfelic = 5 germanare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{133}{46}=2.9$ = domalkalic = 2, monzonase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{68}{65}=1.0$ = sodipotassic = 3, monzonose.

The texture is clearly microscopic trachytic; it is porphyritic with hornblende phenocrysts alone; it is thus alferphyric and should be termed trachiphyro-hornblende-monzonose.

TRACHIPHYRO-BOROLANOSE (SYENITE-PORPHYRY).

Occurrence.—In a number of places in the Highwoods occurs a dike rock which, by reason of its chemical, mineralogical, and textural peculiarities, has a definite place of its own, and in its appearance affords a particular and easily recognizable type. One dike (832) cuts leucite-basalt and breccia near the Shonkin stock at the head of Shonkin Creek; another (783), whose broken down exposure consists of large plate-like slabs, is found in basaltic flows and breccias in the spur running north from the main ridge which terminates in Twin Peaks, just below the central summit on the main ridge; another (861) cuts a black pinnacle of basaltic breccias at the head of a west branch of upper Shonkin Creek, near the Arnoux stock, on the divide to Highwood Creek. One example (703) cuts a spur run-

ning up toward the mountain ridge on the west side of Highwood Gap; another (682) forms the crest of a little hill in the open country south of South Peak. The dike is about 25 feet wide and weathered down. The rock is platy, has rather large phenocrysts of feldspar, and is considerably altered and brownish from weathering. Still another, on the west side of Highwood Gap (697), is much weathered and broken down and cuts a small intrusion of another rock and also the basaltic dikes. These dikes have a width of from 6 to 10 feet and cut the basaltic dikes and breccias. The last example (745) is one of the dikes on the summit ridge leading to South Peak. It is greatly weathered and kaolinized. The feldspar phenocrysts are small, but the microscope shows that the rock belongs in this type.

Megascopic characters.—In the hand specimens these rocks are of a general pearl-gray color. They are distinct porphyries. The phenocrysts consist of numerous tabular alkalic feldspars which attain dimensions of 12 by 2 mm. and are not of very good crystal form, small black glittering prisms of augite, and hexagonal tables of biotite. They are thus to be classed as alfersalphyric in character. These components are in general without arrangement in the gray groundmass, which is evidently granular and made up of a lesser quantity of the tiny femic grains among the salic ones. In two instances, however, the thin tabular feldspar phenocrysts are arranged in a markedly oriented manner parallel to the walls of the dike and show a pronounced flow structure.

None of these occurrences affords perfectly fresh material. The newly fractured rock face is dead and lusterless, the feldspar cleavages lack sparkle, and the larger phenocrysts have a white porcelain-like look which shows that they are more or less altered. These observations do not apply to the alferric minerals, which are generally well preserved. On weathered surfaces the rock exhibits a light-brown crust, and in the more altered occurrences it is brown throughout.

Microscopic characters.—In the thin sections the minerals seen are magnetite, apatite, diopside, biotite, and alkali feldspars. The iron ore and apatite present no especial peculiarities. The mica is a brown biotite of ordinary character. The diopside varies from very pale to a clear green; it rarely shows pleochroism, has a wide extinction angle, and is well crystallized in columnar forms; it is of the regular Highwood type described elsewhere. A few pieces of a pleochroic ægirite-augite were observed in some sections. The feldspars are of the usual character of orthoclase; they undoubtedly contain soda, as shown by the analysis. They are either untwinned, which is common among the phenocrysts, or singly twinned Carlsbads, which are very common in the lath-like development in the groundmass. The phenocrysts vary much in size, not only in the different occurrences, but also in the same section, and there are formal transitions

from phenocryst to groundmass. The phenocrysts in all cases are abundant and thickly scattered. Very few feldspars that could be recognized as of plagioclase would be formed, and as these were in the more altered types the species could not be determined.

In the groundmass the small lath-like feldspars vary considerably in size in the different dikes, but they all have the same form and the trachytic texture, and in general are interwoven without arrangement; in some cases there was seen a tendency to form radial divergent groups, resulting in a fabric suggesting remotely the spherulitic.

The microscope shows that the ferromagnesian minerals are fresh and well preserved, while even in the best material the feldspars are considerably altered and brown with kaolin. This is especially true of those in the groundmass, and this brownish scattered kaolin dust prevents the study of the interspaces between the groundmass feldspars. It may be safely said, however, that there is no quartz, and this fact, combined with the low silica and the presence of some chlorine and sulphuric anhydride in the type analyzed, leads to the suspicion that the rocks when fresh probably contained in these interspaces small amounts of lenad minerals—nephelite, sodalite, and nosean. Some of the larger phenocrysts of feldspar contain colorless isotropic bays and areas of what is probably secondary analcite.

Chemical composition.—For the purpose of chemical examination the rock of the dike cutting the Shonkin stock was selected as the one affording the best material. The analysis, made under the writer's direction by Dr. W. M. Bradley, resulted as shown in the table on the next page.

The features of this analysis are the low silica combined with high lime and alkalies and the predominance of potash over soda. The amount of alteration mentioned is shown by the rather considerable amount of water. As a whole the analysis is typical for the general salic types of the Highwoods, and the analogy of this dike rock with the salic granular stock rocks is seen by comparing it with them. There is given for comparison the analyses of the stock of Middle Peak and of several similar rocks from other parts of the world. The close similarity to the granular rocks of the stocks and the geologic occurrence tend to show that these dikes are intrusions of the same general stage of differentiation in the magma basin below, for just as the salic portions of the stocks break up through the femic ones, so these salic dikes cut the femic dikes. The type above analyzed cuts the femic extrusives near the Shonkin stock.

Analyses of borolanose and related rocks.

	I.	II.	III.	IV.	V.	VI.
SiO_2	51.94	52.05	49.70	47.8	51.02	0.866
Al_2O_3	15.78	15.02	18.45	20.1	18.63	.155
Fe_2O_3	4.07	2.65	3.39	6.7	3.14	.026
FeO	3.17	5.52	4.32	.8	.84	.044
MgO	3.48	5.39	2.32	1.1	1.02	.087
CaO	6.04	8.14	7.91	5.4	7.89	.107
Na_2O	3.44	3.17	5.33	5.5	4.13	.055
K_2O	7.69	6.10	4.95	7.1	6.08	.082
H_2O	2.17	.35	1.34	2.4	1.10	-------
TiO_2	.39	.47	1.33	.7	Tr.	.005
MnO	Tr.	Tr.	Tr.	.8	.59	-------
BaO	.42	.42	-------	.8	CO_2 4.53	-------
SrO	.28	.28	-------	-------	Fl. Tr.	-------
P_2O_5	.59	.21	.40	-------	.16	.004
SO_3	.29	.02	-------	.4	.29	.004
Cl	.08	.24	-------	-------	.09	.002
	99.83	100.03	-------	-------	-------	-------
Less O	.02	.06	-------	-------	.02	-------
Total	99.81	99.97	99.44	99.3	99.64	-------

I. Trachiphyro-borolanose (syenite-porphyry) from dike near Shonkin stock, Highwood Mountains. W. M. Bradley, analyst.

II. Grano-borolanose (basic syenite, syenomonzonite), main type of Middle Peak stock, Highwood Mountains. E. B. Hurlburt, analyst.

III. Borolanose (covite) from schoolhouse, Magnet Cove, Ark. H. S. Washington, analyst. Jour. Geol., vol. 9, 1901, p. 612.

IV. Borolanose (borolanite) from Lake Borolan, Sutherland, Scotland. J. H. Player, analyst. Horne and Teall, Trans. Royal Soc. Edinburgh, vol. 37, pt. 1, 1892, p. 178.

V. Borolanose (phonolite) from Gennersbohl, Hegau, southern Germany. G. F. Föhr, Inaug. Diss., Wurzburg, p. 24, 1883. (Including Cu 0.15 and trace Cr_2O_3.)

VI. Molecular proportions of No. I.

Mineral composition or mode.—The actual quantitative mineral composition or mode of this rock can not be definitely reckoned from the analysis, since the presence of the augite and biotite introduces too many unknown factors. It can not be accurately determined by the microscope because the condition of the feldspathic groundmass does not permit of accurate separation of its component parts. If, however, the groundmass is considered merely as so much feldspar, and no attempt is made to separate the individual microlites or to determine the amount of material in their interspaces, a fairly accurate computation of the other minerals as contrasted with the feldspars may be made by repeated measurements. The results are as follows:

Actual mineral composition of borolanose.

	Measured units.	Volume, per cent.		Specific gravity.				Weight, per cent.
Feldspar	1,841	71.1	×	2.6	=	184.86	=	64.6
Biotite	254	9.9	×	3.0	=	29.90	=	10.4
Diopside	302	11.7	×	3.3	=	38.61	=	13.5
Magnetite	124	4.7	×	5.2	=	24.44	=	8.5
Apatite	68	2.6	×	3.2	=	8.32	=	3.0
Total	2,589	100.0				286.13		100.0

In all 150 measurements were made, giving an average of 17 units on the scale for the grains, feldspars not subdivided into individual microlites. The last column gives the approximate percentage composition by weight.

Classification in prevailing systems.—In the prevailing systems of classification this rock has no very definite position. The alkalic feldspars and ferromagnesian minerals place it in a general way in the syenite family, of which it would be a very basic member. Its chemical composition allies it with the monzonites, from which it is excluded by the lack of plagioclase feldspar. In spite of the high lime, there is molecularly enough ferrous iron and magnesia to convert the lime into diopside and prevent the formation of plagioclase. On the other hand, the presence of a certain amount of the feldspathoid minerals, but not enough to carry it into the nephelite-syenite family, in conjunction with the large amount of ferromagnesian minerals, produces tendencies toward the essexites. On the whole, considering both the minerals and the chemical composition, the name syenite-porphyry would perhaps best suit it, though it is a divergent type of this family.

Classification in the new system.—In the new classification the rock has a definite position, determined by its standard mineral composition calculated from its analysis, as may be seen by the annexed table:

Calculation of the norm of borolanose.

	Analysis.	Molecular ratio.	Or.	Ab.	An.	Ne.	So.	No.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	51.94	0.866	492	108	46	46	6	12	142	15			
Al_2O_3	15.78	.155	82	18	23	23	3	6					
Fe_2O_3	4.07	.026									26		
FeO	3.17	.044							9	4	26	5	
MgO	3.48	.087							62	25			
CaO	6.04	.107			23				71				13
Na_2O	3.44	.055		18		23	4	10					
K_2O	7.69	.082	82										
TiO_2	.39	.005										5	
P_2O_5	.59	.004											4
Cl_2	.08	.002					1						1
SO_3	.29	.004						4					
Rest	2.87												
Total	99.83		82	18	23	23	1	2	71	15	26	5	4

Or	45.59	
Ab	9.43	
An	6.39	71.18
Ne	6.53	
So	.97	
No	2.27	
Di	15.63	
Ol	2.16	
Mt	6.03	25.92
Il	.76	
Ap	1.34	
Rest	2.87	
Total	99.97	

Class, $\frac{\text{Sal}}{\text{Fem}}=\frac{71.18}{25.92}=2.3=$ II, dosalane.

Order, $\frac{\text{L}}{\text{F}}=\frac{9.77}{61.41}=.157=$ lendofelic $=6$, norgare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{137}{23}=5.9=$ domalkalic $=2$, essexase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{82}{55}=1.5=$ sodipotassic $=3$, borolanose.

The calculation shows that the rock is very near the upper limit in its rang; it is thus close to the peralkalic rang laurdalase, in which $Na_2O+K_2O:CaO$ as 7:1 or greater than that. It is, therefore, very near judithose, the sodipotassic subrang of laurdalase, and Washington, in his tables of calculated analyses (p. 295), places it in that subrang, the omission of the small amount of sodalite giving a larger amount of nephelite, and this in turn less anorthite, thus causing it to just fall over the line in judithose.

On account of the condition of the groundmass, which prevents the determination of the actual amount of lenad (feldspathoid) minerals present, a good comparison can not be made between the norm and

the mode of this rock. As shown elsewhere in this paper, in the Highwood rocks olivine and lenad molecules have frequently united to form biotite; the presence of about 10 per cent would cause the rock to be a modal variety of a typical borolanose.

From all that has been said it is clear that in the new system the rock should be termed biotitic trachiphyro-borolanose, which is a very concise expression for a rock in which the feldspathic minerals are present in greater amount than the ferromagnesian ones; in which the alkali feldspars dominate over the plagioclase ones, and both of these over feldspathoids and a small amount of biotite which accompanies normative diopside; in which potash and soda are approximately equal molecularly, and in which the texture is porphyritic, with a trachytic groundmass.

PHYRO-BIOTITE-CASCADOSE (MINETTE OF HIGHWOOD TYPE).

Occurrence.—In the Highwood Mountains are many dike rocks which have a dark basaltic character, with numerous prominent biotite phenocrysts. They may well be characterized by the field name "mica traps" or "mica-basalts." The Highwood rocks do not, as a rule, yield perfectly fresh material in their outcrops. This characteristic is in no type so marked as in the one about to be described. Usually these dikes are greatly weathered and broken down, and often their position is marked merely by heaps of gravelly débris in which are thickly scattered the chloritized plates of biotite forming the large phenocrysts, enabling one to recognize this particular type and distinguish it from the other basaltic dike rocks.

There are so many of these dikes in this area that it would be useless to attempt to give a list and description of all of them. They were found in every stage of preservation, from those just mentioned to a few which afford really good material and are well suited for study and description.

One of these (736) cuts basaltic flows and breccias on the crest of the divide between Lava and Arrow peaks and near the slope of the latter. It is about 6 feet wide and extends in the direction of Middle Peak. Another occurs at the eastern edge of the stock of granular rock on the crest of the Middle Peak–South Peak ridge, and is similar to the former in character. A third (678) is found as a sheet intruded into Cretaceous sandstones at the head of a little fork of Williams Creek in the open country south of the Highwood Mountains. The sheet is 10 to 12 feet in thickness and rests on the sandstone. The drainage has cut through both, forming a small, narrow gulch. The upper part of the sheet has weathered and is crumbly, the lower portion is dense, very tough, and well preserved. It has not altered the beds into which it is intruded. It is noticeable that both in the Middle Peak divide dike (744) and in this occurrence the large, flat micas are oriented in a flow structure, in the dike perpendicularly and

parallel to its vertical walls and in the sheet horizontally and parallel to the bedding. In the plane of these micas the rock splits rather readily. The weathered surface of these rocks shows a brown crust. They have a very massive parting structure, breaking into large, heavy blocks, with a poorly developed spheroidal or "pillow" structure. Sometimes on the surface of the contraction planes zeolites are developed.

Megascopic characters.—On a freshly broken surface the rock is a very dark stone-gray, almost black, with a tendency to conchoidal splintering; the grain is very fine, but not absolutely aphanitic. In the Williams Creek sheet the grain is somewhat coarser and the color somewhat lighter. Thickly scattered in this groundmass are numerous phenocrysts of biotite, whose average cross section measures about 5 mm., but at times reaches 10 mm. They are black and glittering, with bronzy reflections. The prisms and pinacoid (010) are only moderately well developed as a rule, sometimes the clinopinacoid (010) is much longer in its development than the prisms (010). The crystals are rather thin tabular. These large biotites and the basaltic character of the rock produce a strong similarity in habit to the "alnöites."

In addition to these—the characteristic phenocrysts of the rock—there are greenish grains of olivine and occasional but much rarer phenocrysts of a black, well-crystallized augite in moderately stout prisms, which in some cases attain a length of 5 mm. These last two are somewhat variable in the different occurrences.

Microscopic characters.—Under the microscope the minerals seen are apatite, iron ore, diopside, biotite, olivine, feldspars, and feldspathic groundmass products. Apatite is moderately abundant in a few large irregular grains and many small prisms. Iron ore is also abundant in small grains dotting the groundmass.

The pyroxene is a colorless to pale-green diopside without any noticeable pleochroism, of a wide extinction angle, and generally rather long columnar in development. It is well crystallized, with sharp angles and clean faces. It does not contain many inclusions, but some of the very largest crystals are somewhat spongy with inclusions of a brown glass. The small prisms of the groundmass are similar to the larger phenocrysts; various transitions in size between the two occur.

The large biotite phenocrysts are a pale yellowish brown; their pleochroism is not intense. They do not show very good crystal form and are apt to be embayed and ragged on the edges. They also have a narrow mantle around the outer edge, of a much darker color and more intense pleochroism. In these characters they recall the micas of many "minettes," as, for example, those figured by the author[a]

[a]Petrography of the Little Belt Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pl. 76, p. 528.

in such rocks from upper Sheep Creek in the Little Belt Mountains of Montana. Small biotites in thin tablets with sharp outlines are abundant in the groundmass; they have the deep-brown color and intense pleochroism of the border zones of the large phenocrysts.

From what has been said it seems clear that the large micas are of intratelluric origin; that they came up in the magmas into the dike fissures and were oriented parallel to its walls; that during this time they were in part resorbed, but grew again during the final stage of crystallization, adding material of the same character as the smaller crystals forming in the groundmass.

The olivine is somewhat variable; it is most abundant in the Middle Peak divide dike, but is not common; it is less abundant in the Arrow Peak dike, and is almost wholly wanting in the Williams Creek sheet. The few scattered crystals are not large nor particularly well crystallized.

All of these ferromagnesian minerals, both femic and alferric, are fresh and unaltered, except that cracks in the olivine show small lines of serpentinization, and the largest augites in the Williams Creek sheet show some calcite.

The groundmass of these rocks is, relatively to the total amount of phenocrysts, in minor amount, and is somewhat variable in character. It consists chiefly of orthoclase, or, perhaps better, alkali feldspars, in lath-like forms. In the Williams Creek occurrence this is mixed, however, with a subordinate amount of andesine, and in the other two occurrences there is more or less cloudy, feebly polarizing material of indefinite character. As this base is somewhat altered and brown from kaolinization, the exact character of these substances can not be made out. In the Arrow Peak dike it was noticed, however, that some of these areas were outlined by iron-ore grains, bits of pyroxene, mica, etc., into circular forms, and that these were more or less isotropic; and in one of these, in spite of the somewhat kaolinized condition, a cross twinning, exactly like that of leucite, could be made out, especially by the aid of the sensitive tint. In other places plumose bundles of fibers resembling spherulites, and no doubt of zeolitic nature, are seen.

In short, the base, while chiefly alkali feldspar, is accompanied sometimes by small amounts of andesine, sometimes of leucite, sometimes of nephelite, or mixtures of these, somewhat zeolitized and kaolinized.

Chemical composition.—For the purpose of studying the chemical character of these rocks the Arrow Peak dike was selected as the freshest and best. In the next table is given the analysis of this rock, by Dr. H. W. Foote, as well as analyses of related rocks. From these it will be seen that these dikes are of the same general magma

Analyses of biotite-cascadose and related rocks.

	I.	II.	III.	IV.	V.	VI.
SiO_2	46.04	47.88	48.95	48.36	46.73	0.767
Al_2O_3	12.23	12.10	12.98	12.42	10.05	.120
Fe_2O_3	3.86	3.53	3.63	5.25	3.53	.024
FeO	4.60	4.80	4.68	2.48	8.20	.064
MgO	10.38	8.64	11.73	9.36	9.27	.259
CaO	8.97	9.35	7.66	8.65	13.22	.161
Na_2O	2.42	2.94	2.31	1.46	1.81	.039
K_2O	5.77	5.61	3.96	3.97	3.76	.062
H_2O	2.87	2.22	3.16	5.54	1.24	
TiO_2	.64	.77	.49	1.18	.78	.008
MnO	Trace.	.15	.13	.13	.28	
BaO	.48	.46		.29	?	
SrO	.25	.13			?	
P_2O_5	1.14	1.11	.67	.84	1.51	
SO_3	Trace.	None.				.008
Cl	.11	Trace.			.18	.004
	99.76	99.69			100.56	
O=Cl	.03	X .30			.04	
Total	99.73	99.99	100.35	99.93	100.52	

I. Phyro-biotite-cascadose (minette or mica-basalt) from dike near Arrow Peak. H. W. Foote, analyst.

II. Montanose (shonkinite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst. ($X=CO_2$, 0.12; ZrO_2, 0.03; F, 0.05; S, 0.025; Cr_2O_3, 0.035; V_2O_3, 0.04=0.30.)

III. Lamarose (absarokite) from dike at head of Lamar River, Yellowstone Park. L. G. Eakins, analyst. (Iddings, Jour. Geol., vol. 3, pp. 938, 943, 947.)

IV. Absarakose (absarokite) from dike south of Clark Fork, Absaroka Range, Wyoming. L. G. Eakins, analyst. Loc. cit.

V. Shonkinose (shonkinite) from Square Butte. L. V. Pirsson, analyst. Bull. Geol. Soc. America, vol. 6, 1895, p. 414.

VI. Molecular proportions of I.

as the shonkinose (shonkinite) and montanose forming the granular massives of the region, and that their texture and, to a considerable extent, their actual mineral composition have been modified by their physical environment. They are not, therefore, of magmas very different from the stocks which they accompany, but in reality are lamprophyres or differentiated femic dikes, as may be seen by comparison with the salic ones (aplitic or leucocratic forms), thus agreeing with the differentiation seen in the laccoliths and stocks or the massives themselves.

Under the name "absarokite," Iddings,[a] in 1895, described a number of rocks which occur in dikes and flows and which are of basaltic habit, with abundant phenocrysts of olivine and augite in a groundmass consisting of alkali-alumina minerals, chiefly alkali feldspars, with small amounts of plagioclase or leucite or altered feldspathoids, and a second generation of the phenocrystic minerals, sometimes accompanied by biotite. By reference to the foregoing table it will be seen that there is a close general resemblance between absarokites and the cascadose or minette under description, but they differ in minerals and in habit, as the cascadose contains a large amount of biotite in large and abundant phenocrysts. In the new system of classification absarokite appears in a subrang of its own under the order gallare.

Mineral composition or mode.—The quantitative mineral composition differs somewhat from the calculated norm, and the rock can not be said to have a normative mode. This is due to the fact that the greater part of the olivine, some of the magnetite, and some of the feldspathic molecules have united to form biotite. The microscopic analysis of the rock by Rosiwal's method gives the following results:

Mode of phyro-biotite-cascadose.

	Measured units.	Volume, per cent.		Specific gravity.				Weight, per cent.
Feldspar	645	45.4	×	2.6	=	118.0	=	39.2
Biotite	226	15.8	×	3.0	=	47.4	=	15.8
Olivine	98	6.9	×	3.3	=	22.8	=	7.6
Diopside	379	26.7	×	3.3	=	88.1	=	29.3
Magnetite	54	4.0	×	5.2	=	20.8	=	6.9
Apatite	18	1.2	×	3.2	=	3.8	=	1.2
Total	1,420	100.0				300.9		100.0

In the feldspar item there is included not only the alkalic feldspars which make up the bulk of the feldspathic base, but the lenad (feldspathoid) minerals as well. Owing to the conditions of their

[a] Jour. Geol., vol. 3, 1895, p. 935.

admixture and the clouding by kaolinization it is impossible to measure them separately with any degree of certainty, though taken together they can be measured as a whole with ease and accuracy. The results given in the above table are of interest; they appear at first sight to differ considerably from the norm given later, but when examined it will be found that the only important divergence is in the presence of about 16 per cent of biotite which has been formed at the expense of some of the olivine and feldspathic minerals in the norm. If this is true, the weight of the feldspathic minerals plus the olivine in the norm should equal the feldspathic minerals plus the biotite plus the olivine of the mode. This results as follows:

$$\overset{\text{F.}}{48.76}+\overset{\text{Ol}}{13.00}=61.76=\overset{\text{F.}}{39.2}+\overset{\text{Bi}}{15.8}+\overset{\text{Ol}}{7.6}=62.6$$

The result is as close as could be expected. Bearing this fact in mind, it will be seen that on the whole the agreement between the calculation from the chemical analysis and the result of microscopic analysis is reasonably close. About 6 per cent of olivine and about 10 per cent of feldspathic molecules have been united to form about 16 per cent of biotite. In composition biotites vary considerably, as may be seen by reference to tables of analyses of them; the one from the "monchiquite" of Horberig, Oberbergen has about equal parts of olivine and lenad molecules. Splitting the biotite up in the proportions mentioned above, we have the adjoined comparison between the norm obtained from the analysis and from the corrected mode:

Comparison of norm with mode of cascadose.

	Norm.	Mode.
F	48.76	49.2
Ol	13.00	13.4
Di	25.04	29.3
M	6.79	6.9
Ap	2.69	1.2

Had the feldspathic base been fresh and clear, no doubt equally good results could have been obtained from it.

Classification in prevailing systems.—In the prevailing systems these rocks should probably be classed as minettes; they are lamprophyric dikes consisting chiefly of alkali feldspars, biotite, and augite, with abundant phenocrysts of biotite and none of the feldspars. The minettes are not a well-defined group chemically, as may be seen by reference to the table of analyses given by Zirkel,[a] but these types

[a] Lehrbuch der Petrographie, vol. 2, 1894, p. 349.

differ in a considerable degree from the common ones, and the lenad (feldspathoid) minerals found in the base accentuate this point. Their most marked feature is the large biotite phenocrysts, which give them a strong alnöid habit. They might be called the Highwood type of minettes.

Classification in the new system.—In the new classification these rocks belong in the sodipotassic subrang of kamerunase, as may be seen by the calculation of the analysis into its standard mineral composition, shown in the annexed table. The norm derived from this and the classification are given below.

Calculation of the norm of biotite-cascadose.

	Analysis.	Molecular ratio.	Or.	Lc.	Ne.	So.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	46.04	0.767	258	76	62	12	42	228	88			
Al_2O_3	12.23	.120	43	19	31	6	21					
Fe_2O_3	3.86	.024								24		
FeO	4.60	.064						13	19	24	8	
MgO	10.38	.259						101	158			
CaO	8.97	.161					21	114				26
Na_2O	2.42	.039			31	8						
K_2O	5.77	.062	43	19								
TiO_2	.64	.008									8	
P_2O_5	1.14	.008										8
Cl_2	.11	.002				2						
Rest	3.60											
Total	99.76		43	19	31	2	21	114	88	24	8	8

Or	23.91	48.76
An	5.84	
Lc	8.28	
Ne	8.80	
So	1.93	
Di	25.04	47.42
Ol	13.00	
Mt	5.57	
Il	1.22	
Ap	2.69	
Rest	3.60	
Total	99.88	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{48.76}{47.42}=1.0=$III, salfemane.

Order, $\frac{L}{F}=\frac{19.01}{29.75}=.64=$lenfelic$=7$, kamerunare.

Rang, $\frac{Na_2O+K_2O}{CaO'}=\frac{101}{21}=5=$domalkalic$=2$, kamerunase.

Subrang, $\frac{K_2O}{Na_2O}=\frac{62}{39}=1.6=$sodipotassic$=3$, cascadose.

In class it stands at the center point; in order it is not far from the line, and is therefore near portugare; in rang it is near the top, not very far from the peralkalic line, and thus close to subrang 3 in malignase. It differs from montanose in containing smaller amounts of silica and lime, but the main cause of difference in

classification lies in the difference in the relative amount of alkalies and alumina available in felic (feldspathic) and lenic (feldspathoid) molecules, which produces nearly twice as much anorthite in this rock, sufficient to carry it into a domalkalic rang.

Texture and name.—From what has been said it is clear that these rocks are holocrystalline granular, with a finely granular to aphanitic base. In fabric they are porphyritic, and since the dominant phenocryst is biotite they are alferphyric.

In the new classification this subrang under the salfemanes was not named, and in Washington's[a] tables of analyses it was represented by this rock alone. It is therefore proposed to call the subrang cascadose, from Cascade County, Mont., where the type described occurs.

Since the mode is abnormative, and biotite, which is the critical mineral, is alferric and appears largely in phenocrysts, the rock may be designated an alferphyro biotite-cascadose, or more concisely phyrobiotite-cascadose. This is a very concise and definite expression to indicate a rock which is made up of about equal parts of salic and femic minerals, in which the feldspathic dominate over the lenad (feldspathoid) molecules and both together over the anorthite molecule; in which potash and soda are present in approximately the same quantity; in which both femic and salic mineral molecules have united to form a good deal of biotite, and which is megascopically porphyritic with phenocrysts of biotite. The name surely has decided advantages over the somewhat vague term of minette of the older systems.

MONCHIQUOSE (ANALCITE-BASALT).

Introductory.—There exists in the Highwoods a vast number of dikes; indeed, no geologic feature is more characteristic of the group, as has been already explained and shown on the geologic map. Of these dikes a very great number belong to the type about to be described; their field occurrence and characters have been described on pages 31–36.

The rocks of this type were thoroughly investigated by Lindgren,[b] who showed that they contain analcite as a prominent component and under such conditions and with such associations that he was compelled to regard it as a primary mineral. The author, in the subsequent study of these rocks and of closely related types from other localities in Montana, agreed with Lindgren and published a paper,[c] in which Lindgren's ideas were brought out and supported by additional evidence, but it should be remembered that Lindgren first recognized analcite as a possible primary component of igneous rocks, gave the proofs which demonstrate it, and offered the explanation of its mode of formation under such circumstances.

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[a] Chemical analyses of igneous rocks: Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 347.
[b] Eruptive rocks from Montana; Proc. California Acad. Sci., ser. 2, vol. 3, 1890, p, 51.
[c] The monchiquites or analcite group of igneous rocks; Jour. Geol., vol. 4, 1896, p. 679.

Since Lindgren's original paper, which was brief and wanting in some details, is inaccessible to many petrographers, and the study of more abundant and widely distributed material from the Highwoods has brought out new facts, a full description of this type, based partly on Lindgren's studies and partly on those of the author, is given, together with an analysis and a discussion of its position in the new system of classification.

Megascopic characters.—On a freshly fractured surface these rocks are generally a dark greenish black, varying into olive or grayish tones. They are at times thickly dotted with phenocrysts of a stout, well-developed black or greenish-black augite which attains a length of 10 mm. They are also abundantly spotted with round white phenocrysts attaining a diameter of 1 to 2 mm. Rarely small flecks of biotite are visible and sometimes greenish grains of olivine. Sometimes the augite is very conspicuous as a phenocryst and the white crystals are rare; sometimes the reverse is true, the latter are extremely abundant, and the rock assumes a dark-gray color. In the majority of cases both are abundant. Thus in the variance of these two phenocrysts two extremes connected by all degrees of transition are seen. In the geologic description of these rocks in a previous chapter it was stated that the dikes of the region could be divided into three types, one containing prominent phenocrysts of biotite, to which the field name Highwood minette or mica trap could be given and which have been described petrographically as biotite-cascadose; one with phenocrysts of augite (augite-porphyry or augitophyre), and one with phenocrysts of analcite (analcite-basalt). These last two are the extremes of the type under consideration, and although megascopically there is considerable difference between them, petrographically they are the same, their appearance depending on the relative proportions of the augite and white mineral (analcite) which develop as phenocrysts or remain in the groundmass.

Microscopic characters. In thin section the following minerals are seen: Iron ore, apatite, biotite, olivine, augite, and analcite. The iron ore and apatite offer nothing deserving mention. "The olivine is usually sharp edged, clear, and fresh, sometimes surrounded by a narrow border of biotite. When decomposing, a yellowish brown ferruginous serpentine results. A mineral of the spinel group is observed as an inclusion in the olivine."[a]

The augite is of the usual Highwood type, of a pale-green, nonpleochroic color, well crystallized. It often becomes darker green toward the border, from increase, no doubt, of ægirite. The extinction angle is very wide, up to 45° or more, the cleavage good. Forms observed commonly (110), (011), (100), and (111). Twinning on (100) rather common. There is great variation in size from the largest crystals

[a] Lindgren, op. cit., p. 53.

noted to the small microlites of the groundmass. It frequently contains inclusions of glass and magnetite.

In regard to the analcite Lindgren states:

It appears embedded in the groundmass in hexagonal, seldom octagonal—most frequently simply rounded—sections. In size they do not exceed one millimeter, and are frequently much smaller. Most of the crystals are perfectly isotropic, but not quite clear, being clouded somewhat by minute interpositions, which, under large magnifying power, prove to be largely gas, in part also glass inclusions. The former have often a very irregular form. Irregular spots showing a faint double refraction are sometimes noted, more in some sections than in others. Under favorable circumstances an imperfect cleavage in two directions crossing each other perpendicularly may also be noticed. Minute fragments from an exceptionally large crystal melt rather easily and quietly before the blowpipe to a white enamel. In one thin section a large crystal showing irregular octagonal form with very distinct cleavage was selected for experiment. It was uncommonly clear and perfectly isotropic. Hydrochloric acid dissolves it easily upon very slight heating under abundant formation of chloride of sodium. Ignition does not make it opaque and does not produce double refraction. No microscope reaction for Cl or SO_3 could be obtained.

The groundmass of these rocks, in which the above minerals are embedded, consists of minute dark prisms of augite, grains of iron ore, and small analcite crystals, which form a colorless background upon which everything else is displayed. Lindgren remarks with truth that glass is probably not present. Under the conditions in which rocks of such chemical composition have formed it does not seem that glass could be present, any more than in a typical granite.

Discussion of analcite.—That the isotropic mineral described above is actually analcite was shown by Lindgren by the separation of it by heavy fluids and by the analyses of the product obtained. This was performed on two samples, with the results given in I and II of the appended table.

Analyses of analcite.

	I.	II.	III.	IV.
SiO_2	54.90	49.87	52.38	0.873
Al_2O_3	23.30	22.55	22.92	.225
Fe_2O_3	Trace.	1.51	.75	.005
CaO	1.90	2.62	2.26	.041
MgO	.70	1.28	.99	.025
Na_2O	10.40	10.92	10.66	.173
K_2O	1.60	2.66	2.13	.022
H_2O	7.50	11.05	7.50	.417
Cl	None.	Trace.		
SO_3	None.	None.		
Total	100.30	102.46	99.59	

Since these analyses were made on very small quantities the ordinary analytical errors become appreciable, and therefore the average of the two would undoubtedly be more correct than either alone, as the errors would tend to balance one another. The determination of water in II was made on only 0.1 gram and is evidently too high, and may be excluded. The average is shown in III and its molecular ratios in IV. The lime, iron, and magnesia are due to admixed microlites of pyroxene, and deducting sufficient silica to turn them into a silicate of the general formula $RO.SiO_2$ the remaining ratios have the following relation:

SiO_2	0.802	=	4.00	=	4
Al_2O_3	.225	=	1.12	=	1
K_2O+Na_2O	.195	=	.97	=	1
H_2O	.417	=	2.08	=	2

This gives the analcite formula Na_2O, Al_2O_3, $4SiO_2$, $2H_2O$, some of the soda being replaced by a little potash, as often happens.

It is thus shown that the products obtained by Lindgren and analyzed by Melville were undoubtedly analcite; but the author has been interested to discover, if possible, whether leucite might also be present. As mentioned by Lindgren, it is clear that the material is not sodalite or nosean, and its form precludes an alteration from nephelite. On the other hand, it has been shown on a previous page, under the heading "Leucite-shonkinose," that in the fresh rock of the East Peak stock both leucite and analcite occur simultaneously, and reasons are given for considering the latter a primary mineral. Under the microscope leucite might be present and not distinguishable from analcite.

For this purpose a specimen from a dike on Arrow Peak was selected which corresponds very closely with the foregoing description of the type. The isotropic phenocrysts are of a very pale-brownish tone, and some of them have a few tiny inclusions of iron ore arranged in one or two concentric circles, suggesting the arrangement seen in leucite. Under crossed nicols occasional spots of faint double refraction were seen. These suggestions of leucite caused the selection of the sample. All the other minerals are perfectly fresh and normal.

The rock was crushed, sifted, the dust washed out by suspension in distilled water, and after a large amount of magnetite had been extracted with the magnet the powder was placed in the potassium mercuric iodide solution. The specific gravity of the solution was then regularly lowered and determined, and the resulting precipitates collected and examined. At first, of course, all the pure augite and remaining magnetite fell, and after this the same minerals containing

some white material were precipitated. The succeeding precipitates were as follows:

No. 1. Specific gravity, 2.56; very little, impure.
No. 2. Specific gravity, 2.52; very little, impure.
No. 3. Specific gravity, 2.45; very little, impure.
No. 4. Specific gravity, 2.40; some, lighter in color.
No. 5. Specific gravity, 2.36; more, purer.
No. 6. Specific gravity, 2.32; large amount, quite pure.
No. 7. Specific gravity, 2.28; nearly all the remainder, very pure.

The first four portions were very small in amount and were contaminated with particles of the dark femic minerals, chiefly augite. These became less, but not until 2.36 was reached did they practically disappear. It was thought that if at 2.45 anything came down in noticeable amount it could be analyzed and the question whether it was leucite be determined. From 2.56 to 2.36, however, the portions obtained were entirely too small and impure for analysis; they evidently consisted of compound grains of substances above 2.56 and below 2.36, which were mingled in varying proportions and gradually fell as the specific gravity of the liquid was lowered. Below 2.32 a pure product was left which contained by far the greater part of the white salic component of the rock. The analyses in Lindgren's work render it unnecessary to make a new one of this material; it can be nothing else than analcite, and as qualitative tests showed water, soda, and alumina as its main constituents, this point may be regarded as settled.

As the result of this examination, then, it can be said with confidence that in the sample selected analcite is certainly the dominant mineral, and leucite can be present in only very minute amounts, if at all; therefore, Lindgren's conclusion that in dikes in the Highwoods there is a rock type composed of augite, iron ore, olivine, and analcite, with these minerals all fresh and all crystallized in their own characteristic forms, is confirmed.

In the author's opinion it would not be correct to conclude that necessarily all the rocks which show round white phenocrysts, and which are so abundant in the Highwoods, are pure analcite rocks. The analysis of a specimen from Highwood Gap shows a considerable amount of potash, and no mineral which might contain potash except leucite or its alteration products. The same is true for the basaltic surface lavas described later. Furthermore, the sheets about Square Butte and the Shonkin Sag laccolith, which megascopically and microscopically are similar to the rocks under discussion, are very evidently intruded portions of the shonkinite magmas of those occurrences whose textural development has been determined by the physical conditions attending their crystallization and solidification.

Their white phenocrysts should be regarded in large part as pseudoleucites. Regarding this rock, Lindgren says:[a]

In some specimens of the rock in question the larger part of the colorless mineral is faintly doubly refracting, showing bluish gray colors between crossed nicols. The crystals are then not so well defined and often take the form of rounded spots separated by the groundmass and small porphyritic augites and olivines. These rounded spots between crossed nicols divide into irregular, sometimes also regular, triangular fields. I regarded this (see Vol. XV, Tenth Census U. S.) as double refracting analcite. When isolated it has the specific gravity of analcite and, according to an analysis of impure material, a similar composition, although the percentage of silica is too low. No chlorine or sulphur. Specific gravity, 2.24.

It should be noticed that the rocks in which this variety occurs are perfectly fresh, even more so than those containing the isotropic mineral; the olivine and augite show no trace of decomposition.

In the analcite-basalts, as described here, there is no evidence of decomposition, except that the olivine is occasionally converted into yellowish brown serpentine. In other specimens, however, it is seen that the analcite offers but slight resistance to decomposition. Needles of a zeolite with vivid colors of interference, probably stilbite, penetrate the analcite in all directions, and soon every crystal is transformed into an aggregate of zeolites. Large stilbite crystals are found in the decomposing rock. The augite is much more resistant and frequently remains intact when all the other constituents have been entirely decomposed.

The author is inclined to believe that these doubly refracting areas are in part pure analcite, in part pseudoleucites, and the zeolitic alteration proceeds in both, the zeolite being perhaps in part stilbite, but also in large part natrolite and possibly other zeolites as well.

In summation the author believes that some of these rocks, which appear so much alike in hand specimens, are pure primary analcite-basalts; some are primary analcite- and leucite-basalts, and in some these minerals have suffered secondary zeolitic and pseudomorphic alterations. He sees no reason why primary analcite and leucite should not be present in the same rock. It is difficult to imagine how part of the leucite should have changed to analcite and part not, if all the minerals are otherwise fresh, and the crystal form and occurrence of the analcite negatives the view that it is secondary after any other mineral (see p. 111).

The primary nature of analcite as a rock-forming mineral, brought out by Lindgren and the author, has been recognized by many petrographers,[b] and its occurrence and mode of formation are so thoroughly

[a] Proc. California Acad. Sci., 2d ser., vol. 3, p. 56.

[b] Cross, Analcite-basalt from Colorado: Jour. Geol., vol. 5, 1897, p. 684.
Washington, Am. Jour. Sci., 4th series, vol. 6, 1898, p. 182.
Brögger, Ganggefolge des Laurdalits, 1897, p. 103.
Card and Mingaye, Records Geol. Surv. New South Wales, 1902, vol. 7, pt. 2, p. 93.
Evans, Quart. Jour. Geol. Soc., vol. 57, 1901, p. 38.
Ogilvie, Jour. Geol., vol. 10, 1902, p. 500.
Lacroix, Roches alcalines d'Ampasindava: Nouv. Arch. du Muséum, 4th series, vol. 1, 1902, p. 197.
Pirsson, Am. Jour. Sci., 4th series, vol. 13, 1902, p. 161.

discussed that further reference to this point is unnecessary. The writer would only remark, in passing, that this view must not be carried too far, and that while some analcite seems undoubtedly primary, a great deal must undoubtedly be secondary. There is presumably a stage in rock crystallization where, as the earlier components are separated, there gradually results a mother liquor composed of silica, alumina, alkalies, and water, which will crystallize into feldspars, feldspars and quartz, or feldspathoids and analcite, with partial or complete exclusion of the water vapor, according as proportions and conditions vary. The transition is not sharp between this stage and that where the attacking of the earlier components by the excluded vapors with formation of new minerals (pneumatolytic stage) probably begins. The view as to whether certain compounds are primary or secondary must in many cases be largely a subjective one. The general view is that secondary minerals are those formed from previously existent ones, but how shall we classify those formed from a glass—by devitrification proceeding from aqueous vapors?[a]

Chemical composition.—To determine the chemical composition of these rocks and their relation to the other magmas of the region, a fresh example of average type from a dike on the east side of the very summit of the divide in Highwood Gap was analyzed by Doctor Foote, with the results given in I. Two analyses of similar rocks from the neighboring Little Belt Mountains are given for comparison, and it will be seen that chemically they are very much like this rock. Some other analyses from other petrographic areas also show a strong general resemblance. The analysis of the dark rock of the Shonkin Sag laccolith is presented for comparison of the shonkinoid magmas of the Highwood area. They are much alike except in the relations of the alkalies.

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[a] This inquiry becomes more pertinent since Morozewicz, in a very complete and able investigation of some monchiquoid rocks (Ganggesteine des Bezirk's von Taganrog: Mem. du Com. Géol. St. Petersburg, vol. 8, 1903, p. 45), suggests that the analcite which they contain is produced by the weathering of a glass which happened to have the composition of analcite, minus the water. This interesting paper reached the writer after this bulletin had been handed in for publication, and he regrets that he is able only to notice it by this note in the revision.

Analyses of monchiquose (analcite-basalt) and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	47.82	48.39	48.35	45.59	41.10	43.39	47.83	0.797
Al_2O_3	13.56	11.64	13.27	12.98	14.82	16.67	12.10	.131
Fe_2O_3	4.73	4.09	4.38	4.97	2.35	3.47	3.53	.030
FeO	4.54	3.57	3.23	4.70	10.38	8.80	4.80	.063
MgO	7.49	12.55	8.36	8.36	9.43	7.30	8.64	.187
CaO	8.91	7.64	9.94	11.09	10.56	8.79	9.35	.159
Na_2O	4.37	4.14	3.35	4.53	3.94	3.30	2.94	.070
K_2O	3.23	3.24	3.01	1.04	1.28	2.17	5.61	.034
H_2O+	3.37	2.56	2.89	3.40	2.31	2.67	1.52	.187
H_2O-	......	.28	.90	.51	.39	.29	.70	......
CO_2	......	None.	.30	......	.26	.39	.12	......
TiO_2	.67	.73	.52	1.32	3.20	2.20	.77	.008
P_2O_5	1.10	.45	.40	.91	.19	.41	1.11	.008
SO_3	Trace.	.08	......	......	.09	.19	None.	......
Cl	.04	Trace.	......	.05	Trace.	.02	Trace.	......
Cr_2O_3	......	.07	Trace.	......	Trace.	Trace.	.04	......
NiO	......	None.	.04	......	Trace.	Trace.	Trace.	......
MnO	Trace.	Trace.	.19	.14	.14	.19	.15	......
BaO	.16	.32	.54	.13	.06	.02	.46	......
SrO	.21	.15	.09	.12	Trace.	Trace.	.13	......
Fl	......	......	.25	......	......	......	.05	......
ZrO_2	......	......	......	.03	......	......	.03	......
	100.20	99.90	100.01	99.87	100.50	100.28	99.99	......
O=F	......	......	.11	......	......	......	......	......
Total	......	......	99.90	......	......	......	......	......

I. Monchiquose (analcite-basalt) from dike on east side Highwood Gap. H. W. Foote, analyst.

II. Analcite-basalt from Bandbox Mountain, Little Belt Mountains, Montana. W. F. Hillebrand, analyst. Twentieth Ann. Rept. U. S. Geol. Surv., pt. 3, 1900, p. 545.

III. Monchiquose (analcite-basalt) from Big Baldy Mountain, Little Belt Mountains, Montana. W. F. Hillebrand, analyst. Loc. cit., p. 548.

IV. Monchiquose (analcite-basalt) from The Basin, Cripple Creek, Colorado. W. F. Hillebrand, analyst. W. Cross, Jour. Geol., vol. 5, 1897, p. 689.

V. Analcite-basalt from Fernhill dike, Sydney, New South Wales. H. P. White, analyst. Records Geol. Surv. New South Wales, 1902, vol. 7, p. 93.

VI. Analcite-basalt from Bondi boss, Sydney, New South Wales. J. C. H. Mingaye, analyst. Loc. cit.

VII. Montanose (shonkinite) from Shonkin Sag laccolith, Highwood Mountains. W. F. Hillebrand, analyst.

VIII. Molecular proportions of I.

Mineral composition or mode.—The mineral composition can be found by calculation from the analysis. It is as follows:

Mineral composition or mode of monchiquose.

Leucite	14.8
Analcite	30.0
Augite	35.2
Olivine	8.0
Iron ore	8.2
Apatite	2.6
Rest	1.2
Total	100.0

Classification in prevailing systems.—In these, if one follows the law of priority, Lindgren's name should stand and this rock would be termed analcite-basalt, or if leucite is also present, as in the above, analcite-leucite-basalt. In Rosenbusch's system its occurrence in lamprophyric dikes must be taken into account, and the rock falls into the camptonite-monchiquite-alnöite series and would be an analcite-leucite-monchiquite.

Classification in the new system.—In this its systematic position is seen in the following computation of its norm and position:

Calculation of the norm of monchiquose.

	Analysis.	Molecular ratio.	Or.	Ab.	Ne.	So.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	47.82	0.797	204	204	68	3	56	210	53			
Al_2O_3	13.56	.131	34	34	34	1	28					
Fe_2O_3	4.73	.030								30		
FeO	4.54	.063						12	13	30	8	
MgO	7.49	.187						93	94			
CaO	8.91	.159					28	105				26
Na_2O	4.37	.070		34	34	2						
K_2O	3.23	.034	34									
TiO_2	.67	.008									8	
P_2O_5	1.10	.008										8
Cl_2	.04	.001				1						
Rest	3.74		34	34	34	1	28	105	53	30	8	8

Or	18.9	54.7
Ab	17.8	
An	7.8	
Ne	9.7	
So	.5	
Di	23.4	42.1
Ol	7.9	
Mt	7.0	
Il	1.2	
Ap	2.6	
Rest	3.7	
Total	100.5	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{54.7}{42.1}=1.3=$III, salfemane.

Order, $\frac{L}{F}=\frac{10.2}{44.5}=0.23=$lendofelic$=6$, portugare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{104}{28}=3.7=$domalkalic$=2$, monchiquase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{34}{70}=0.49=$dosodic$=4$, monchiquose.

The texture is eminently porphyritic; the mode is abnormative, with analcite as the critical mineral; the rock may thus be termed phyro-analcite-monchiquose. If it is thought desirable to indicate that both salic and femic phenocrysts are present the rock may be termed salfemphyro-analcite-monchiquose. This is a very concise expression to indicate a rock which consists of about equal proportions of light and dark minerals, which has a certain general chemical composition, in which the ordinary silico-aluminous alkalic minerals are replaced by analcite, and which has a porphyritic texture with phenocrysts of analcite and augite.

PETROGRAPHY OF EXTRUSIVE FLOWS, BRECCIAS, AND TUFFS.

GENERAL PETROGRAPHIC DESCRIPTION.

The extrusive rocks occurring in the Highwoods are readily divided into two groups—the light-colored feldspathic salic rocks, which for field purposes have been roughly classed as andesites, and the dark augitic rocks or basalts.

Feldspathic lavas and tuffs.—Those of the first group are dense rocks of a very light color, usually a pale brown inclining to gray, sometimes a light gray. Close examination shows that they are very apt to contain streaky portions or broken angular fragments whose form is distinguished by a slightly different color or texture from the inclosing matrix. These are clearly flow breccias—portions of the lava which after having solidified have been broken again by movements of the viscous mass and kneaded through it without remelting. Close inspection of them also shows in many cases small black shining specks, minute crystals of an iron-bearing mineral.

When these rocks have been greatly weathered and perhaps subjected to heat and steam from later effusions of lava, they assume darker colors with reddish tones, owing to the oxidation of the iron mineral, and in some such cases—as, for instance, at the head of Little Belt Creek and on upper Briar Creek—they are of a strong, almost brick, red color.

Where ash beds or fine tuffs of these feldspathic lavas occur, as on the Middle Peak divide, they have the same light-gray color, but are even and dense and are indurated to very dense compact rock masses, often with a platy structure; in these cases they are not easily distinguished from fine-grained, light-colored sandstones.

Basaltic lavas.—Basaltic lavas occur in a much greater variety of forms than the preceding. They appear as dense and compact, either with or without embedded porphyritic minerals, as amygdaloids, as scoriaceous lava, and as conglomerates or breccias.

The compact basalts are in places black or greenish-black rocks, as on the Pinewood Peak saddle; at other places they are dark stone gray and sometimes platy, as on Arrow and Lava peaks. As they

become lighter in color the embedded minerals or phenocrysts make their appearance. The rocks are sometimes thickly stippled with tiny white specks of what is generally an altered leucite, or pseudoleucite. They have a pin-pricked appearance, resembling certain well-known leucite-bearing rocks of the Eifel district in Germany. In other examples these pseudoleucites are much farther apart and much larger, having the size of medium-coarse shot. They are regularly sprinkled through the rock and many dark-green prisms of augite accompany them. A gray-colored example of this type collected on the upper slopes of the basin west of the Arnoux stock, whose waters flow into Shonkin Creek opposite North Peak, so exactly resembles specimens of the leucitophyre of Rieden by the Laacher See in the Eifel district of Germany that one can scarcely be distinguished from the other.

Amygdaloidal basaltic lavas.—The amygdaloidal lavas vary in color from medium to dark gray; in some cases the amygdules are as large as hazelnuts, but generally they are about the size of peas and are rather thickly scattered through the rock. They are solid and composed of fibrous zeolites, usually natrolite and stilbite. Sometimes they are flattened ovoids arranged in layers and lines showing movement which occurred in the viscous mass before the formation of the zeolites and which drew out and extended the steam pores in which the zeolites were subsequently deposited. This type of lava is common in the masses composing Lava and Arrow peaks.

In another type the amygdules are about the size of small shot and thickly scattered through the rock. They are white and so closely resemble the pseudoleucite phenocrysts that except on very minute inspection it is difficult to tell them apart. The lens shows that they are gray with a faint pink tone and fibrous, while the pseudoleucites are greenish and granular. This type is found abundantly on Pinewood Peak.

In all of these amygdaloidal lavas the rock is more or less altered; if olivine occurs it is converted into a dark-red opaque substance; often the augites are changed, but they appear to have withstood the action of the heated waters and vapors and weathering better than any of the other original minerals.

Scoriaceous basaltic lavas.—These are closely related to the foregoing, differing only in that the steam cavities are not filled with zeolites. The slopes of Arrow and Lava peaks are composed largely of a débris of fragments of scoriaceous and at times almost pumiceous vesicular lava, varying in color from dark stone gray to deep mahogany red. The only definite recognizable mineral to be seen in this material is the augite in black glittering prisms.

While part of it may be the upper surface of flows, a large portion of it is projected matter, varying from ash and lapilli to bombs of considerable size.

Basaltic tuffs and breccias.—These are dark-colored rocks, sometimes dark gray or dark brown, but commonly of a chocolate color. The tuffs or ash beds are fine in texture and compact, showing considerable induration; they have a dull, hackly fracture, on whose surfaces are many glimmering points of light reflected from minute fragments of crystals. The breccias are made up of the same material, but embedded in them are innumerable bits of rock, some angular, others somewhat rounded. Among these the most common are pieces of baked, reddened, and hardened shale, and of the leucitic lavas previously mentioned. The included chunks are of all sizes up to a foot or so in diameter. In some cases, as in material collected on upper Highwood Creek about a mile north of the Highwood Gap divide and near the large wall dike, the inclosed pieces are rounded sufficiently to produce the appearance of a volcanic conglomerate.

The ash beds and breccias described are found all over the eastern and northern parts of the mountains and as isolated or prolonged patches among the sedimentary foothills, as on upper Davis and Aspen creeks.

For the purpose of detailed investigation of the petrographic character of the rocks composing the effusive masses, types of the feldspathic and basaltic lavas described above have been selected for study and analysis—in each case the freshest and best material that could be found. The greater part of the ejected Highwood matter is unsuited by various processes of alteration for petrographic investigation, but in a considerable number of instances reasonably fresh material of both kinds was found. The study of the thin sections has shown that, from the standpoint of advanced classification, practically only two types are present, as already roughly determined in the field and shown on the geologic map.

The sections show, it is true, a slight variation in the specimens collected from different parts of the field, as will be mentioned later, but nothing that would warrant further separation. Under prevailing systems of classification the types would be latite (trachyandesite) and leucite-analcite-basalt; under the new system they are adamellose and shonkinose.

TRACHIPHYRO-HORNBLENDE-ADAMELLOSE (LATITE OR TRACHY ANDESITE).

Occurrence.—The best appearing material of the lighter colored feldspathic lavas was found on the north side of the upper reaches of North Willow Creek as it issues from the mountains. As may be seen by reference to the geologic map, the feldspathic lavas are prolonged in this direction outward from the mountain mass and form bold projecting masses and crags. On these exposed surfaces the effusive character of the material is clearly shown by flowage lines which dip away from the mountains and have the wavy, twist-

ing nature so often seen in lavas. At the same time the rock has a clearly brecciated character, angular chunks of various sizes being brought out in the weathering. The appearance indicates clearly that it is a flow breccia, the first cooled and solidified crust having been broken up and rolled in angular fragments through the still viscous moving mass.

Megascopic characters.—On a broken surface the rock is a pale-purplish brown or light-chocolate color spotted with angular fragments of a slightly different tone of the body color, but in some cases of a dull gray. The contrast and the brecciated character are not marked. The fragments on the average are of about the size of a hazelnut. The rock is dotted with small dark specks of a ferromagnesian mineral which often shows a lustrous cleavage surface.

Microscopic characters.—In thin section the microscope discloses the following minerals: Iron ore, apatite, hornblende, biotite, labradorite, alkali feldspar, quartz (?), and glass.

Iron ore is not common. It occurs in the usual small grains and is more abundant in some brecciated areas than in others. The apatite is seen in the common small prismatic crystals and shows no especial features.

The hornblende is very abundant, though it occurs in greater quantity in some areas than in others. It occurs in short, stout prisms, bounded, when well crystallized, by 110, 010, and 111; long slender ones are rare. The cleavage, as usual, is marked. It has a rather striking and remarkable color and pleochroism.

$\mathfrak{c}$ =deep orange-red, inclining to brownish in some specimens.
$\mathfrak{b}$=orange.
$\mathfrak{a}$=pale to lemon-yellow.

The inclination to brownish tones is somewhat variable, not only in the different specimens but according to the strength of the illumination. It is to be noted that these colors are deepest in those specimens which, by reason of a ferruginous pigment distributed through them, have megascopically strong reddish tones. Since the mineral appears uniform and homogeneous, it is difficult to think that the color is the result of alteration or staining; on the other hand, the hornblende is of the common green variety in specimens collected at the little canyon of Highwood Creek above the Cretaceous part of its valley, near the Shonkin stock, and at the head of Little Belt Creek on the south slopes of Pinewood Peak. At the last-named locality the green crystals contain occasional spots of the red type, so that from the evidence at hand it does not appear certain whether the more common red kind is an alteration of the green or not. In this connection it is of interest to note that where the hornblende is deep red the biotite, which is a rare constituent occurring in small phenocrysts like the hornblende, also shows so nearly the same colors in its

pleochroism that it is distinguished from the hornblende with difficulty. In the red variety the angle c on $\mathfrak{c}$ is nearly zero and the double refraction is not very strong.

The labradorite is the next most striking mineral. It does not occur as a phenocryst, but is confined to the groundmass, where it appears as short laths which vary in size, ranging from some that are almost as large as small phenocrysts to very minute ones. Carlsbad and albite twinning are common and afford excellent sections for determining the ratios of An to Ab. A number of measurements showed that Ab_3An_4 is the labradorite present; there were one or two which gave Ab_7An_8. These laths are in some cases bent in the viscous flow structure.

The alkali-feldspar appears also in small laths and in fragments distinguished from the labradorite by lack of twinning, lower birefringence, and parallel extinction. The sections are too small for detailed observations.

This mesh of interwoven minerals is surrounded by films of a low or nonpolarizing substance. In some cases, especially around the alkali-feldspar sections, high powers show "pepper and salt" mantles, which might have become micrographic or micropoikilitic areas if the scale on which they crystallized had been larger; these areas resemble devitrified acid (quarfelic) glasses in appearance. In other places these mantles are not seen, and the whole arrangement suggests a final remnant of glass in the quickly crystallizing flow which has since then partially devitrified in places, giving rise to quartz and alkali feldspar, though the scale is too small for direct proof.

To make sure that a feldspathoid was not present instead of glass, the rock was treated with nitric acid, but no gelatinous silica could be obtained.

Varieties of the type.—In the different specimens collected are some variations which are worth noting. Those in the hornblende have been described above. In the material from the head of Little Belt Creek was observed some quartz in scattered angular pieces; the labradorite appears more distinctly as a phenocryst, and the groundmass is more largely composed of the "pepper and salt" aggregate of minute quartz and alkali feldspar. In some specimens from Briar Creek a few crystals of sporadic augite well crystallized and of a brownish tone were noted; augite occurs also in the acidic (perfelic) extrusive material at the debouchment of Highwood Creek previously mentioned, and the groundmass of this rock is more felt-like than in the one last described, though it is still exceedingly minute. The material from the Shonkin stock has rather more feldspar and less hornblende.

Mineral composition or mode.—The mineral composition was ascertained by Rosiwal's method. The fine feldspars could not, however, be measured separately, and all of the feldspar was therefore lumped into areas and the glass or residual material was included. Two traverses, a and b, give the following results. It will be noticed

that biotite was observed only once, and therefore constitutes an unimportant constituent. The very fine needles and tiny granules of apatite could not well be measured and were disregarded. The analysis proves that 0.7 per cent must be present. The chief value of the determination is that it shows the relation between the hornblende and the feldspars.

Table showing the calculation of the mode of adamellose.

	Iron ore.	Hornblende.	Feldspar, etc.	Biotite.	Total.
$a, \frac{\text{mm.}}{100}$ meas	21	159	1,024	6	1,210
$b, \frac{\text{mm.}}{100}$ meas	26	228	1,088	0	1,342
$a+b, \frac{\text{mm.}}{100}$ meas	47	387	2,112	6	2,552
a, No. meas	15	43	50	1	109
b, No. meas	17	54	56	0	127
$a+b$, No. meas	32	97	106	6	236
a, per cent	1.7	13.1	84.6	0.5	99.9
b, per cent	1.9	16.9	81	0	99.8
$a+b$, per cent	1.8	15.1	82.7	0.3	99.9

It is impossible to determine the relative amounts of plagioclase, orthoclase, and quartz or glass, and these must be taken collectively.

Chemical composition.—This is shown in I of the following table of analyses. It is like many andesoid rocks, but the considerable amount of potash is to be noted. Since biotite and other potash-bearing silicates are absent, except orthoclase, there must be about 25 per cent of that mineral present, or at least capable of forming. Compared with similar rocks of other regions, the only one that closely resembles it with regard to adamellose is the one from Thibet described by Bäckström. The type that seems to be most like it chemically is one on the border between monzonose and adamellose, shown in III. Under the name "vulsinite" Washington described Italian lavas which contained abundant labradorite in addition to the alkali feldspars of trachytes, and which mineralogically resemble the present rock. An analysis of one of these is shown in IV. Like the Willow Creek rock, the rock contains considerable lime and potash. Ransome proposed the term "latite" for all effusive rocks "standing chemically about midway between the andesites and trachytes;"[a] this definition would include the Willow Creek rock. An analysis of a typical latite is shown in V, and it has an essential resemblance to the other analyses.

If this effusive is compared with any of the granular deep-seated

[a] Loc. cit. infra., p. 375.

masses of the district, the one to which it has the nearest resemblance is the shoshonose or monzonite of Highwood Peak. The latter is a less siliceous rock and contains more lime, iron, and magnesia. The material around Pinewood Peak unquestionably belongs to the Highwood Peak center of eruption, and this type thus stands as intermediate between the shoshonose or monzonite and the pulaskose or syenite, and represents a less differentiated stage than either of them. This would tend to show that it is also older, and when one considers the relative geologic and topographic positions of the rock masses this idea appears to be confirmed.

Analyses of adamellose or trachyandesite and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	59.24	61.45	57.04	55.69	56.78	51.00	0.987
Al_2O_3	13.84	14.36	13.66	19.08	16.86	17.21	.134
Fe_2O_3	5.46	2.75	4.96	4.07	3.56	2.41	.034
FeO	1.36	4.61	1.77	3.26	2.93	4.23	.019
MgO	4.79	2.73	4.43	3.41	3.41	6.19	.120
CaO	5.60	4.34	6.23	6.87	6.57	9.15	.100
Na_2O	3.13	3.98	3.08	2.89	3.19	2.88	.050
K_2O	4.22	3.75	4.95	4.41	3.48	4.93	.044
H_2O+	2.02	.87	1.10	.17	1.21	.63	.112
H_2O-			1.11		.15		
TiO_2	.22	1.37	.94		1.15	.13	.003
P_2O_5	.34		.63		.42	.33	.002
SO_3	.08					.14	
Cl	.04					Trace.	
MnO	Trace.		.17	Trace.		Trace.	
BaO	Trace.		.22			.34	
SrO			Trace.			.14	
			NiO .07		CO_2 .18		
Total	100.34	100.21	100.36	99.85	99.89	99.60	

I. Adamellose (trachyandesite) from North Willow Creek. Highwood Mountains, Montana. E. B. Hurlburt and B. Barnes, analysts.

II. Adamellose (bronzite-andesite) from Thibet. H. Bäckström, analyst. (Pet. Mitt., Erg. Hft. No. 131, p. 2.)

III. Monzonose-adamellose, (mica-basalt), from Santa Maria basin, Ariz. W. F. Hillebrand, analyst. Iddings, Bull. Philos. Soc. Wash., vol. 12, 1892, p. 212.

IV. Shoshonose (biotite-vulsinite) from Monte Santa Croce, Rocca, Monfina, Italy. H. S. Washington, analyst. Jour. Geol., vol. 5, 1897, p. 252.

V. Shoshonose (augite-latite) from Clover Meadow, Tuolumne County, Cal. G. Steiger, analyst. Ransome, Am. Jour. Sci., 4th series, vol. 5, 1898, p. 363.

VI. Shoshonose (monzonite) from Highwood Peak. E. B. Hurlburt, analyst.

VII. Molecular proportions of I.

Texture.—This has been partly indicated in the foregoing. Megascopically these rocks are firm, compact, and between the trachytic and felsitic in character, and they are porphyritic only on close inspection. They are actually microtrachytic and almost microporphyritic.

Classification in the new system.—The position of this type in the new classification is found in the following calculation of its norm:

Calculation of the norm of adamellose.

			Or.	Ab.	An.	Di.	Hy.	Mt.	Il.	Ht.	Ap.	Qtz.
SiO_2	59.24	0.987	264	300	80	106	67					170
Al_2O_3	13.84	.134	44	50	40							
Fe_2O_3	5.46	.034						16		18		
FeO	1.36	.019						16	3			
MgO	4.79	.120				53	67					
CaO	5.60	.100			40	53					7	
Na_2O	3.13	.050		50								
K_2O	4.22	.044	44									
TiO_2	.22	.003							3			
P_2O_5	.34	.002									2	
H_2O, etc	2.14											
Total	100.34		44	50	40	53	67	16	3	18	2	170

Or	24.5	72.0
Ab	26.2	
An	11.1	
Qz	10.2	
Di	11.4	25.8
Hy	6.7	
Mt	3.6	
Il	.5	
Ht	2.9	
Ap	.7	
Rest	2.1	
Total	99.9	

Class, $\frac{\text{Sal.}}{\text{Fem.}}=\frac{72.0}{25.8}=2.8=$ II, dosalane.

Order, $\frac{Q}{F}=\frac{10.2}{61.8}=0.17=$ quardofelic $=4$, austrare.

Rang, $\frac{K_2O'+Na_2O'}{CaO'}=\frac{94}{40}=2.3=$ domalkalic $=2$, dacase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{44}{50}=0.88=$ sodipotassic $=3$, adamellose.

The comparison of the norm with the mode shows that the diopside and hypersthene of the norm, and perhaps also some of the iron ore and soda (i. e., albite), are replaced in the mode by hornblende. The amounts do not exactly correspond, but this is probably due to the fact that in diopside a much larger amount of lime is needed than in hornblende, and in the mode this lime appears as anorthite. The alumina needed for anorthite might be supplied from albite, the soda of the latter going into the hornblende with iron. On account of the 15 per cent of the alferric mineral hornblende, the mode is an abnormative one.

The textural characters have been already given; they are expressed

by the term trachiphyro. In the new system the rock should therefore be termed trachiphyro-hornblende-adamellose.

Classification in prevailing systems.—Casual study of this rock under the microscope alone would determine it as a hornblende-andesite. When the analysis is considered and it is perceived how much of the orthoclase molecule must be present, it can not be considered a typical andesite, but must assume an intermediate position between the andesites and trachytes, and is therefore a trachyandesite, or, if Ransome's proposed term be employed, a hornblende-latite.

PHYRO-SHONKINOSE (ANALCITE-LEUCITE-BASALT).

Occurrence.—Perfectly fresh unchanged material of the basaltic extrusives has not been found in the area. The difficulty in some cases of distinguishing between the outcrops of dikes and the effusives which they cut has been previously alluded to. The dikes are not far from the original surface, and there was no marked difference in physical conditions, consequently in minerals and texture they closely resemble the flow rocks, to which no doubt they gave origin. There is any amount of vesicular, scoriaceous, and amygdaloidal lava, all more or less altered, but for investigation it was desired to have a compact and, as far as might be, fresh lava, and at the same time to avoid material concerning which there might be some doubt as to its dike nature. For this purpose the basalt flow on the saddle between Highwood and Pinewood peaks was selected. It is by no means ideal material, as will be seen, but it is as good as the district affords, and serves a satisfactory purpose for the study of this effusive magma.

Megascopic characters.—In the hand specimen the rock has the ordinary gray-black compact basaltic appearance. Close inspection shows numerous small, dark, augite prisms as phenocrysts. The fracture is rough and hackly. In places small threads and irregular spots of a white substance are seen, indicating some secondary material deposited in it. It is mostly calcite.

Microscopic characters.—In thin section the rock is seen to consist of phenocrysts of augite, altered olivine, and leucite (and analcite) in a base consisting of a smaller generation of leucite, iron ore, and a greenish glass. The augite is of the usual greenish Highwood type, full of glass inclusions; it is fairly well crystallized, unaltered, and attains a length of 2 mm. The leucite shows the ordinary outlines of this mineral; it is entirely free from the usual inclusions and does not show the multiple twinning structure, due probably to its rather small size, as the crystals do not exceed 0.4 mm. in diameter. Its fractures are filled with calcite and a greenish material of a chloritic nature, substances which have wandered in from the groundmass. Where this greenish substance is present there is a feeble aggregate

polarization between crossed nicols; elsewhere the mineral is completely isotropic. There are irregular and often elongated areas of a colorless, limpid, isotropic substance of low refractive index and distinct cubic cleavage; these are undoubtedly analcite. It is observed that some of the polygonal-shaped sections also have a cubic cleavage, and these may be leucites altered to analcite, but this seems doubtful. The chemical analysis and the microscopic study prove clearly that both of these minerals are present, but since neither shows any marked individuality, it is impossible to distinguish clearly between them.

Olivine is not a common mineral; it is not present as unchanged material, since it is completely altered to a black substance and recalls certain resorption pseudomorphs. It is readily recognized by the characteristic sections and rough cross cleavage; the cracks are filled with greenish chloritic substance.

The glassy groundmass is in part idiochromatic; in part colorless of itself, but it is completely filled with the greenish chloritic dust, which colors it pale green. It is also filled with the dots and rods of black iron ore so commonly seen in partially crystallized femic lavas. Under low power this combines into an aggregate which appears as a greenish-brown base.

Chemical composition.—An analysis of this type, by Doctor Foote, is given under I in the table on the next page.

The analysis shows the characteristics of the Highwood magmas, as may be seen by reference to II, one of the granular rocks of the stocks, and III, the same kind of magma in dike form; the latter, however, shows a different relation of the alkalies, a fact discussed under the description of that type. The type which in some other regions seems to bear the closest resemblance to this rock is a leucite-bearing effusive from Khoi, Persia, whose analysis has been previously quoted and is here repeated. For the sake of comparison, analyses of two other leucitic rocks are given, and it will be noted that they have a much higher ratio of soda to potash than the one under discussion. This is generally true, and in the present case is due to the considerable quantity of analcite present.

Analyses of phyro-shonkinose (leucite-basalt) and related rocks.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	47.98	49.59	47.82	49.65	46.51	46.06	0.798
Al_2O_3	13.34	14.51	13.56	14.39	11.86	10.01	.130
Fe_2O_3	4.09	3.51	4.73	4.21	7.59	3.17	.026
FeO	4.24	5.53	4.54	3.48	4.39	5.61	.058
MgO	7.01	6.17	7.49	6.27	4.73	14.74	.175
CaO	9.32	9.04	8.91	10.12	7.41	10.55	.166
Na_2O	3.51	3.52	4.37	3.21	2.39	1.31	.056
K_2O	5.00	5.60	3.23	5.46	8.71	5.14	.053
H_2O+	2.10	1.95	3.37	2.37	2.45	1.44	.113
H_2O-	-------	-------	-------	-------	1.10	-------	------
CO_2	1.24	-------	-------	-------	-------	-------	------
TiO_2	.58	.36	.67	-------	.83	.73	.008
P_2O_5	1.03	.15	1.10	.79	.80	.21	.007
SO_3	Trace.	.02	Trace.	-------	Trace.	.05	------
Cl	.21	.13	.04	-------	.04	.03	.006
CuO	-------	-------	-------	-------	Trace.	-------	------
NiO	-------	-------	-------	-------	.04	-------	------
MnO	Trace.	Trace.	Trace.	.25	.22	Trace.	------
BaO	.50	.49	.16	-------	.50	.32	------
SrO	.14	.21	.21	-------	.16	.20	------
	100.29	100.78	100.20	•100.19	99.73	99.57	------
Cl=O	.07	.03	.01	-------	.01	.01	------
Total	100.22	100.75	100.19	-------	99.72	99.56	------

I. Shonkinose (leucite-basalt) from saddle between Highwood and Pinewood peaks. H. W. Foote, analyst.

II. Leucite-shonkinose (leucite-shonkinite) from East Peak stock, Highwood Mountains. E. B. Hurlburt, analyst.

III. Monchiquose (analcite-basalt) from dike in Highwood Gap. H. W. Foote, analyst.

IV. Shonkinose (leucitophyre) from near Khoi, Persia. J. Steinecke, analyst. Zeit. Naturw. Halle, vol. 6, 1887, p. 12.

V. Chotose (leucitite) from Bearpaw Peak, Bearpaw Mountains, Montana. H. N. Stokes, analyst. Weed and Pirsson, Am. Jour. Sci., 4th series, vol. 2, 1896, p. 147.

VI. Missourote (missourite) from Shonkin stock, Shonkin Creek, Highwood Mountains. E. B. Hurlburt, analyst.

VII. Molecular proportions of No. 1.

Mineral composition or mode.—The mineral composition can not be determined with exactness because of the impossibility of distinguishing between small leucites and analcites, and in certain areas between these and the isotropic base. The latter is also specked with iron ore and other minerals in form too minute for measurement. Making due allowance for these things, the following table shows a measurement determination made with as careful estimations as possible:

Mode of shonkinose.

Minerals.	Units measure.	Volume, per cent.		Specific gravity.				Weight, per cent.
Iron ore	55	4.0	×	5.2	=	20.80	=	4.17
Apatite	19	1.3	×	3.2	=	4.16	=	1.57
Calcite	26	1.9	×	2.7	=	5.13	=	2.00
Olivine	122	9.0	×	3.4	=	30.60	=	11.81
Augite	225	16.5	×	3.3	=	54.45	=	20.98
Leucite	176	12.9	×	2.4	=	30.96	=	11.92
Analcite	129	9.5	×	2.2	=	20.90	=	8.07
Base	608	44.7	×	2.3	=	102.81	=	39.69
Total	1,360	99.8		---		269.81		100.21

The ratios of the femic minerals to one another and to the salic ones plus the base are the most nearly correct of this determination, which, on the whole, gives a fair idea of the relative quantities of the minerals present.

Classification in prevailing systems.—In these the rock is of course a leucite-basalt in which part of the leucite is replaced by analcite, which appears to be of secondary origin. It resembles very strikingly the leucite-basalts of the Bearpaw Mountains, described some years since by the writer. The fact that the olivine is not present as such by reason of its resorptive alteration does not change the classification and throw it into the leucitites; its chemical composition shows that it belongs in the former group.

Classification in the new system.—The position of this type in the new system is shown in the following calculation, which gives its norm and place:

Calculation of the norm of shonkinose.

	Analysis.	Molecular ratio.	Or.	Ab.	Ne.	An.	Di.	Ol.	Mt.	Il.	Ap.
SiO_2	47.98	0.798	318	66	90	42	244	38	----	----	----
Al_2O_3	13.34	.130	53	11	45	21	----	----	----	----	----
Fe_2O_3	4.09	.026	----	----	----	----	----	----	26	----	----
FeO	4.24	.058	----	----	----	----	15	9	26	8	----
MgO	7.01	.175	----	----	----	----	107	68	----	----	----
CaO	9.32	.166	----	----	----	21	122	----	----	----	23
Na_2O	3.51	.056	----	11	45	----	----	----	----	----	----
K_2O	5.00	.053	53	----	----	----	----	----	----	----	----
TiO_2	.58	.008	----	----	----	----	----	----	----	8	----
P_2O_5	1.03	.007	----	----	----	----	----	----	----	----	7
Cl_2	.21	.003	----	----	----	----	----	----	----	----	3
Rest	4.06	----	----	----	----	----	----	----	----	----	----
Total	100.29	----	53	11	45	21	122	38	26	8	7

Or	29.47	53.85
Ab	5.76	
An	5.84	
Ne	12.78	
Di	26.83	42.11
Ol	5.68	
Mt	6.03	
Il	1.22	
Ap	2.35	
Rest	4.06	
Total	100.02	

Class, $\frac{\text{Sal}}{\text{Fem}}=\frac{53.85}{42.11}=1.2$=III, salfemane.

Order, $\frac{\text{L}}{\text{F}}=\frac{12.78}{41.07}=0.31$=lendofelic=6, portugare.

Rang, $\frac{Na_2O'+K_2O'}{CaO'}=\frac{109}{21}=5.1$=domalkalic=2, monchiquase.

Subrang, $\frac{K_2O'}{Na_2O'}=\frac{53}{59}=0.9$=sodipotasic=shonkinose.

This shows that the rock is a shonkinose, as its chemical composition at once indicates. It is interesting to observe that the norm shows no leucite whatever, but in its place orthoclase associated with nephelite. This arises from the fact that leucite and analcite replace them in the mode, and water plays its rôle. These relations are easily seen in the following equation:

Orthoclase. Nephelite. Water. Leucite. Analcite.

$$K_2Al_2Si_6O_{16}+Na_2Al_2Si_2O_8+2H_2O=K_2Al_2Si_4O_{12}+Na_2Al_2Si_4O_{12}.2H_2O.$$

That is, as water vapor was present analcite was formed and reduced what otherwise would have been orthoclase to leucite. This relation has been previously discussed in the description of the shonkinose of East Peak, and its bearing on the primary origin of the analcite has been pointed out. In the present case, however, there is evidence which was lacking in that rock. In this rock the leucites have their own definite crystal form and are evidently primary. They did not crystallize as orthoclase, to be reduced later on; they are not pseudomorphs; they are original. But if they are original, is not the analcite original also? It is the same question as in the East Peak case.

The texture of the rock is porphyritic, and it is therefore a phyroshonkinose.

CHAPTER VII.

GENERAL PETROLOGY OF THE HIGHWOOD REGION.

INTRODUCTION.

As a group the Highwood rocks show certain features which serve to bring them into a definite family and to distinguish them from rock groups of other regions. The fact that a complex of igneous rocks from a given region may possess what may be termed "clan" characters is now so well known to all petrographers that it is unnecessary to dwell upon the fact. Service to the science at present is best rendered by bringing to light so large a number of such clans that sufficient data may be obtained to enable petrologists to reduce this relation of igneous rocks to definite order and understanding.

In some groups this clan character is best expressed in the relations of the minerals to one another, or in the texture or production of a certain mineral or minerals through the series. In other cases it is best shown by chemical characters which persist through a number of magmas. In the Highwood rocks it is exhibited in part by the mineral and in part by the chemical composition. It is, of course, understood that the mineral pecularities are dependent on the chemical composition combined with the physical conditions under which the magmas cooled and crystallized. For this reason the general chemical character of the Highwood magmas will be considered first.

CHEMICAL CHARACTERS OF HIGHWOOD MAGMAS.

For consideration of this subject twenty analyses are available. They are given in the tables following. Of these analyses, VI is calculated from the microscopic mineral analysis, confirmed as previously shown by a partial chemical analysis; XIII is a partial analysis in which TiO_2 and P_2O_5 have been weighed with alumina; the rest are accurate modern chemical analyses, made according to the latest approved methods. By them practically every considerable rock mass and kind of rock in the district is represented.

Analyses of Highwood rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	65.54	57.18	56.45	59.24	58.04	53.47	55.23	51.00	51.75	52.05
Al_2O_3	17.81	18.54	20.08	13.84	17.25	12.43	18.31	17.21	14.52	15.02
Fe_2O_3	.74	3.65	1.31	5.46	2.49	6.19	4.90	2.41	5.08	2.65
FeO	1.15	1.15	4.39	1.36	1.24	3.73	2.06	4.23	3.58	5.52
MgO	.98	.69	.63	4.79	1.79	3.07	1.85	6.19	4.55	5.39
CaO	1.92	2.31	2.14	5.60	3.50	7.23	3.63	9.15	7.04	8.14
Na_2O	5.55	4.48	5.61	3.13	3.37	3.40	4.02	2.88	2.93	3.17
K_2O	5.58	8.58	7.13	4.22	10.06	7.59	6.43	4.93	7.61	6.10
H_2O+	.54	2.10	1.51	2.02	1.95	......	1.84	.63	2.25	.35
H_2O-	......	......	.26	......	......	......	......	......	......	......
CO_2	......	......	......	......	......	.40	......	......	......	......
TiO_2	.11	.30	.29	.22	.30	1.19	.42	.13	.23	.47
P_2O_5	Trace	.05	.13	.34	.22	.84	.58	.33	.18	.21
SO_3	......	.06	......	.08	Trace.	.62	.23	.03	Trace.	.02
Cl	......	.77	.43	.04	Trace.	......	.32	Trace	.05	.24
MnO	......	Trace.	.09	Trace.	Trace.	......	Trace.	Trace	Trace.	Trace.
BaO	......	.49	......	Trace.	......	......	.46	.34	.30	.42
SrO	......	Trace.	......	......	......	......	Trace.	.14	.07	.28
	99.92	100.35	100.45	100.34	100.21	100.16	100.28	99.60	100.14	100.03
O=Cl	......	.17	.10	.01	......	......	.08	......	.01	.06
Total	99.92	100.18	100.35	100.33	100.21	100.16	100.20	99.60	100.13	99.97

I. Pulaskose (syenite) from Highwood Peak. L. V. Pirsson and W. L. Mitchell, analysts. (712.)[a]

II. Pulaskose (tinguaite-porphyry) from dike at edge of Middle Peak stock. H. W. Foote, analyst. (746.)

III. Pulaskose (sodalite-syenite) from Square Butte. W. H. Melville, analyst. (767.)

IV. Adamellose (trachyandesite) from flow North Willow Creek. E. B. Hurlburt, analyst. (787.)

V. Highwoodose (tinguaite-porphyry) of Highwood type from great dike below Highwood Gap. E. B. Hurlburt, analyst. (724.)

VI. Highwoodose (nosean-syenite) from south side of Highwood Gap. Microscopically calculated, L. V. Pirsson, analyst. (683.)

VII. Monzonose (gauteite) from dike on upper Aspen Creek. H. W. Foote, analyst. (854.)

VIII. Shoshonose (monzonite) from Highwood Peak. E. B. Hurlburt, analyst. (715.)

IX. Fergusose (fergusite) from Arnoux stock at head of Shonkin Creek. E. B. Hurlburt, analyst. (827.)

X. Borolanose (basic syenite) from Middle Peak stock. E. B. Hurlburt, analyst. (739.)

[a] The numbers are those of the original collection.

Analyses of Highwood rocks.

	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.
SiO_2	51.94	50.11	50.00	47.88	49.59	47.98	46.73	47.82	46.04	46.06
Al_2O_3	15.78	17.13	19.36	12.10	14.51	13.34	10.05	13.56	12.23	10.01
Fe_2O_3	4.07	3.73	3.87	3.53	3.51	4.09	3.53	4.73	3.86	3.17
FeO	3.17	3.28	2.67	4.80	5.53	4.24	8.20	4.54	4.60	5.61
MgO	3.48	2.47	2.18	8.64	6.17	7.01	9.27	7.49	10.38	14.74
CaO	6.04	5.09	4.96	9.35	9.04	9.32	13.22	8.91	8.97	10.55
Na_2O	3.44	3.72	3.63	2.94	3.52	3.51	1.81	4.37	2.42	1.31
K_2O	7.69	7.47	8.52	5.61	5.60	5.00	3.76	3.23	5.77	5.14
H_2O+	2.17	4.47	3.53	1.52	1.95	2.10	1.24	3.37	2.87	1.44
H_2O-	------	------	.46	.70	------	------	------	------	------	------
CO_2	------	------	------	.12	------	1.24	------	------	------	------
TiO_2	.39	.82	(a)	.77	.36	.58	.78	.67	.64	.73
P_2O_5	.59	.67	(a)	1.11	.15	1.03	1.51	1.10	1.14	.21
SO_3	.29	.08	------	None.	.02	Trace.	------	Trace.	Trace	.05
Cl	.08	.07	------	Trace	.13	.21	.18	.04	.11	.03
Cr_2O_3	------	------	------	.03	------	------	------	------	------	------
NiO	------	------	------	Trace	------	------	------	------	------	------
MnO	Trace	Trace.	------	.15	Trace.	Trace.	.28	Trace.	Trace	Trace.
BaO	.42	.63	------	.46	.49	.50	(?)	.16	.48	.32
SrO	.28	.35	------	.13	.21	.14	(?)	.21	.25	.20
	99.83	100.09	99.18	99.99	100.78	100.29	100.56	100.20	99.76	99.57
O=Cl	.02	.02	------	------	.03	.05	.04	.01	.03	.01
Total	99.81	100.07	99.18	99.99	100.75	100.24	100.52	100.19	99.73	99.56

[a] In Al_2O_3.

XI. Borolanose (syenite-porphyry) from dike at edge of Shonkin stock. W. M. Bradley, analyst. (832.)

XII. Borolanose (basic syenite) from Palisade Butte. H. W. Foote, analyst. (772.)

XIII. Borolanose (basic syenite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst (partial anal.) (1006.)

XIV. Montanose (shonkinite) from Shonkin Sag laccolith. W. F. Hillebrand, analyst (including ZrO_2=0.03; F=0.05; S=0.03; Cr_2O_3=0.03; V_2O_3=0.04). (1004.)

XV. Leucite-shonkinose (leucite-shonkinite) from East Peak stock. E. B. Hurlburt, analyst. (760.)

XVI. Shonkinose (leucite-basalt) from flow on saddle between Highwood and Pinewood peaks. H. W. Foote, analyst. (799.)

XVII. Shonkinose (shonkinite) from Square Butte. L. V. Pirsson, analyst. (765.)

XVIII. Monchiquose (analcite-basalt) from dike on east side Highwood Gap. H. W. Foote, analyst. (687.)

XIX. Biotite-cascadose (Highwood minette) from dike on Arrow Peak. H. W. Foote, analyst. (736.)

XX. Missourote (albanose) or missourite from Shonkin stock, head of Shonkin Creek. E. B. Hurlburt, analyst. (824.)

A study of these analyses shows at once that the magmas are generally low in silica, which ranges from 65 to 46 per cent, but in the majority of types is about 50 per cent. Alumina is present in about average amount, and runs from 20 to 10 per cent. With diminishing silica and alumina the lime, iron, and magnesia rise. The most interesting and important relations are to be seen in the alkalies. There is some variation in the ratios of soda to potash, but in general the potash predominates. In some cases, especially in the siliceous and in the most femic or basic magmas, this predominance of potash is marked. It is to be noted also that high alkalies occur with high lime—for example, in one case K_2O 7.5, Na_2O 3.0, and CaO 7.0 per cent, respectively. This combination, the alkalic character with high lime and potash, is the distinctive feature of the Highwood magmas, which runs through the whole family and gives it a distinctive petrographic stamp.

That this is an uncommon feature in rock magmas is clearly seen in Washington's tables of analyses, where perpotassic and dopotassic rocks are rare. In speaking of this, Washington remarks[a] that of the whole number of analyses the perpotassic and dopotassic taken together form only 5.1 per cent, the perpotassic only 0.5 per cent. The Highwood analyses contribute a considerable proportion of these magmas. Outside of the central Montana province the only regions in which rocks so high in potash are found, so far as the writer knows, is in Italy and in the Leucite Hills of Wyoming.

In the table of analyses there is one exception, XVIII, the monchiquose dike, in which soda predominates. This may have been caused by a secondary enrichment in soda.

The parent magma of the Highwoods—the source from which these types sprung—must have possessed the same general characters as the types themselves. It was thus of a very definite nature and its probable composition will be discussed in a later portion of this chapter.

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[a] Prof. Paper U. S. Geol. Survey No. 14, p. 104.

NORMS OF HIGHWOOD ROCKS.

The chemical character of the rocks is, of course, seen also in the following tables of their calculated norms. The order in which these norms are given is the same as in the preceding table of analyses. On examining this table the feature that first attracts attention is the general dominance of orthoclase over albite—a dominance that increases toward the femic end of the series, and at this end there is only one marked exception. Toward this end also as the silica falls the orthoclase is eventually replaced by leucite. These facts show the strongly potassic nature of these magmas. Like the increase in nephelite, augite, olivine, and apatite toward the femic end, they are the result of expressing in mineral form the series of chemical analyses previously given, and show, of course, similar distinctive features. The manner in which the iron ores range through the group with small variations in percentage is also an interesting feature.

Taken as a whole the series shows also how gradually rocks merge into one another chemically and mineralogically, and how arbitrary must be lines of distinction based on these properties. The group affords also in several ways an excellent illustration of the new system of classification. These features are much more clearly seen by comparing the norms than by comparing the analyses. Thus the first three are of pulaskose; alkali feldspars are the chief components; small quantities of other minerals occur, but play very subordinate rôles. In adamellose alkali feldspars are the most important, but are associated with considerable quantities of quartz, anorthite, and diopside. In highwoodose alkali feldspars with some diopside are again the chief minerals, all the rest being in subordinate amounts, and the notable feature is the very great preponderance of orthoclase over albite. In monzonose the albite and orthoclase are equal, and the notable increase in anorthite is the chief feature. In shoshonose the series is becoming distinctly more femic, the alkali feldspars are balanced by an equal amount of anorthite and diopside, while nephelite and olivine are not insignificant. Next comes fergusose, a new type of remarkable texture, consisting of orthoclase, nephelite, and diopside; the great preponderance of the orthoclase is, as in highwoodose, the distinctive feature, and one that separates it from the norms of rocks formerly classed as nephelite-syenites, since the latter contain quantities of soda which expresses itself in large amounts of nephelite, albite, or both.

Calculated norms of Highwood rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Orthoclase	32.7	50.6	42.3	24.5	59.5	45.0	37.8	28.9	45.0	36.1
Albite	46.7	25.2	28.3	26.2	14.7	13.1	31.4	10.0	3.7	7.3
Anorthite	7.0	6.7	9.7	11.1	3.1	------	12.8	19.5	3.9	9.2
Quartz	7.3	------	------	10.2	------	1.4	------	------	------	------
Leucite	------	------	------	------	------	------	------	------	------	------
Nephelite	------	------	3.4	------	1.7	------	1.4	8.0	11.4	7.4
Sodalite	------	5.8	6.0	------	4.9	------	------	------	------	2.9
Noselite	------	------	------	------	------	5.7	------	------	------	------
Diopside	2.0	3.7	------	11.4	9.7	17.4	1.1	19.4	23.75	24.5
Olivine	------	------	5.9	------	------	------	------	8.3	1.5	6.2
Hypersthene	2.7	------	------	6.7	------	------	4.1	------	------	------
Wollastonite	------	------	------	------	.4	1.9	------	------	------	------
Magnetite	1.2	2.8	1.9	3.6	3.0	7.7	5.6	3.5	7.4	3.9
Ilmenite	.2	.6	.6	.5	.6	2.3	.8	.2	.5	.9
Hematite	------	1.8	------	2.9	.3	------	1.1	------	------	------
Apatite	------	------	.3	.7	.3	2.0	1.3	.7	.3	.3
Acmite	------	------	------	------	------	2.8	------	------	------	------
Hyalophane	------	------	------	------	------	------	------	------	------	------

I. Pulaskose from Highwood Peak.
II. Pulaskose from dike at Middle Peak.
III. Pulaskose from Square Butte.
IV. Adamellose from flow on North Willow Creek.
V. Highwoodose from dike north of Highwood Gap.
VI. Highwoodose from south of Highwood Gap.
VII. Monzonose from dike on upper Aspen Creek.
VIII. Shoshonose from Highwood Peak.
IX. Fergusose from Arnoux stock, Shonkin Creek.
X. Borolanose from Middle Peak stock.

Calculated norms of Highwood rocks.

	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.
Orthoclase	45.0	44.5	49.5	33.4	33.4	29.5	22.2	18.9	23.9	1.1
Albite	9.4	9.4	------	------	.5	5.8	1.6	17.8	------	------
Anorthite	6.1	8.1	8.9	3.3	7.8	5.8	8.3	7.8	5.8	5.3
Quartz	------	------	------	------	------	------	------	------	------	------
Leucite	------	------	.9	------	------	------	------	------	8.3	22.7
Nephelite	6.0	11.1	16.8	13.4	13.4	12.8	6.3	9.7	8.8	5.9
Sodalite	1.0	------	------	------	1.9	------	1.0	------	1.9	------
Noselite	2.8	.7	------	------	------	------	------	.5	------	------
Diopside	16.7	10.2	10.8	28.4	29.1	26.8	37.9	23.4	25.0	36.7
Olivine	1.8	2.2	.8	9.1	5.7	5.7	11.4	7.9	13.0	18.6
Hypersthene	------	------	------	------	------	------	------	------	------	------
Wollastonite	------	------	------	------	------	------	------	------	------	------
Magnetite	5.8	5.3	5.6	5.1	5.1	6.0	5.1	7.0	5.6	4.6
Ilmenite	.7	1.5	.9	1.5	.8	1.2	1.5	1.2	1.2	1.4
Hematite	------	------	------	------	------	------	------	------	------	------
Apatite	1.0	1.7	.7	2.7	.3	2.4	3.7	2.6	2.7	.3
Acmite	------	------	------	------	------	------	------	------	------	------
Hyalophane	------	------	------	------	------	------	------	------	------	1.4

XI. Borolanose from dike, Shonkin stock.
XII. Borolanose from Palisade Butte.
XIII. Borolanose from Shonkin Sag laccolith.
XIV. Montanose from Shonkin Sag laccolith.
XV. Shonkinose from East Peak stock.
XVI. Shonkinose from flow, Pinewood Peak saddle.
XVII. Shonkinose from Square Butte.
XVIII. Monchiquose from dike, Highwood Gap.
XIX. Cascadose from dike, Arrow Peak.
XX. Missourote (albanose) from Shonkin stock.

This is followed by borolanose, of which there are four examples, X to XIII; orthoclase is still the chief ingredient, but there is a considerable increase in the soda minerals, albite and nephelite, and also in anorthite. In montanose there is a great increase in augite and olivine, but there is only 3 per cent of anorthite. The rock is thus composed of alkalic feldspars and lenads, potash strongly dominating, with ferromagnesian minerals; it is peralkalic. This lesser amount of anorthite distinguishes montanose from the next type, shonkinose, which contains enough anorthite to carry it over the line into the domalkalic rang—monchiquase, but, as the norms show, the montanose and shonkinose are very close together. In XVIII, the exceptional type of the region, the preponderance of the sodic minerals carries the rock into the dosodic subrang monchiquose and differentiates it from shonkinose. In the next norm, that of cascadose, the large proportion of lenad minerals, as compared with feldspar, carries us into a different order, the lenfelic one under salfemane, kamerunare; leucite begins to appear, and this finds an important position in albanose (missourote). The latter, it will be remembered, on account of the predominance of augite and olivine, stands on the very border line of the next class, dofemane.

GEOLOGIC OCCURRENCE OF THE DIFFERENT MAGMAS.

The geologic occurrence of the magmas is by no means the same as the geologic occurrence of the rocks, for the rocks are the result of not only the chemical properties but the physical environment of the magma. Thus, as is well known, the same magma in different modes of occurrence produces rocks which differ in minerals and texture. This is illustrated in a general way in the Highwoods. Thus, for instance, the intrusive stock of East Peak, the dike of Highwood minette (cascadose) of Arrow Peak, and the basaltic effusive (shonkinose) of Pinewood Peak saddle are from practically the same magma, with slight variations, as may be seen in the following comparison:

Comparison of rocks different in geologic occurrence but similar in chemical composition.

	East Peak stock.	Arrow Peak dike.	Pinewood Peak flow.
SiO_2	49.6	46.1	48.0
Al_2O_3	14.5	12.2	13.3
Fe_2O_3	3.5	3.7	4.1
FeO	5.5	4.6	4.2
MgO	6.2	10.3	7.0
CaO	9.0	9.0	9.3
Na_2O	3.5	2.4	3.5
K_2O	5.6	5.8	5.0

The intrusive rock (fergusite) of the Arnoux stock and the dike (syenite-porphyry or borolanose) at the edge of the Shonkin stock have practically the same magma.

Comparison of chemical composition of stock and dike.

	Stock.	Dike.
SiO_2	51.8	51.9
Al_2O_3	14.5	15.8
Fe_2O_3	5.1	4.1
FeO	3.6	3.2
MgO	4.6	3.5
CaO	7.0	6.0
Na_2O	2.9	3.4
K_2O	7.6	7.7

Other instances might be adduced, but these are sufficient to show that there is no peculiar relation in this area between the chemical composition of the magmas and their geologic mode of occurrence. Whatever be their origin below, the same material has been forced upward into both the stocks and the dikes and has appeared in effusive form on the surface. The dikes therefore do not appear to be diaschistic in the sense of Brögger[a]—that is, they are not complementary; they are rather aschistic. It appears to the writer, however, that the stocks themselves show diaschistic features and that in the sense of Brögger both stocks and dikes, and the laccoliths as well, belong to the same category and represent "laccolithic differentiation." This is treated later in this work.

It may then be stated that in the Highwoods neither the dikes nor the flows represent any more highly differentiated forms of magmas than do the stocks which they accompany. Special cases may be selected in which types on the one hand more salic, and on the other more femic, than some particular stock would appear, but this does not affect the general truth of the statement. On the contrary, the most highly differentiated types which the district affords—the pulaskose (syenite) of Highwood Peak and the albanose (missourite) of the Shonkin stock—are both granular rocks occurring in the stocks themselves.

STOCKS AND LACCOLITHS.

Without discussing at this point the general question of the origin of igneous rocks, it may be pointed out that the occurrence of two distinct types, such as the syenite (pulaskose) and monzonite (shoshonose) of Highwood Peak in the canal of such an evident volcanic

[a] Grorudit-Tinguait-Serie, 1894, p. 153.

center can not fail to be of great interest. In the same way the occurrence of shonkinite with kernels of syenite in the laccoliths has an important bearing on the question of differentiation in igneous magmas, a bearing which has already been discussed by various authors. The general advance which has been made in solving problems of this character during the last ten years has led the writer to modify in some degree his earlier views in regard to the laccoliths in the Highwoods. These modifications have been in part given under the geologic description of Square Butte and will be mentioned in the following discussions.

RELATIVE VOLUMES OF THE DIFFERENT MAGMAS.

In a general way the magmas may be roughly divided into two main groups—salic and femic, or acid and basic, or basaltic and trachytic, to give a choice of terms. The areal mapping and field study shows that in this area the amount of the salic magmas compared with the femic is small. This is seen in a variety of ways. It is shown by the dikes, as it is safe to say that for one salic dike there are twenty femic of the same size. It is also seen in the effusive materials—the flows and breccias—the total volume of the femic far exceeding that of the salic, in spite of the fact that the latter, being overlain by the femic, have been saved from erosion, while the femic have in considerable volume disappeared. The same fact is shown in the stocks, the volume of Highwood syenite being smaller than the monzonite, yet it is one of the largest masses of salic rock in the district. The other stocks do not show any strictly salic types, being salfemic in composition. But the most striking evidence is found in the laccoliths, which are worth some attention, as they afford interesting data in this connection which may be used in several directions and in the elucidation of their structure.

SHONKIN SAG LACCOLITH.

If it is assumed that this laccolith is a short section of a cylinder with a diameter of a mile and an average height of 150 feet, it contains very nearly 3,000,000,000 cubic feet of rock. If it is assumed that the mass of augite-syenite (borolanose) which forms the kernel has a diameter of 2,000 feet and an average thickness of 50 feet, it would have a volume somewhat over 150,000,000 cubic feet, in round numbers; that is, the syenite constitutes about one-twentieth of the whole mass. These figures are, of course, approximate (see p. 47). They can not, however, be very far from the truth, and for the purpose they are just as valuable as if they were exact. The point is that there is in the laccolith about 19 times as much shonkinite (montanose) as syenite (borolanose). The bearing of these proportions will be brought out in a later paragraph.

SQUARE BUTTE.

By reference to the cross section of this laccolith given on page 54 it will be seen that it can not be considered as having an exactly cylindrical shape. A considerable portion of the shonkinite has been lost by erosion, but if it is assumed that the laccolith has the form and cross section given, the relative volumes generated by such figures of revolution around a common vertical axis may be computed. This has been kindly done for me by Prof. J. Barrell, who obtained the volume by multiplying the area on one side of the axis by the distance passed over by its center of gravity in the revolution about the axis, both analytic and graphic methods being used as checks. The result of this is as follows:

	Cubic mile.
Total volume of the laccolith	0.69
Inner volume of syenite	.13
Outer volume of shonkinite	.56

That is to say, the syenite comprises 18.8 per cent of the laccolith and the shonkinite 81.2 per cent, thus showing, as previously stated, that the femic magmas are in large excess.

PALISADE BUTTE.

At Palisade Butte there is no such sharp line of demarcation between the light and dark portions. Moreover, the amount of erosion has been so great that the laccolith can not be restored beyond imagining that it had a form similar to that of Square Butte. Enough remains, however, to show clearly that the volume of the dark shonkinite is (and was) much greater than that of the lighter-colored rock.

DIFFERENTIATION IN LACCOLITHS.

From the proportions just given in the case of Square Butte and the Shonkin Sag laccolith some interesting and important relations may be deduced. If one believes that these three laccoliths, with their varied and peculiar structures, present good examples of the results of differentiation, it would be also natural to think, since they stand close together in a group, that they had been formed from a common magma and in toto should be similar in composition. Since the chemical composition of the parts and their relative volumes are known the composition of the original magma is easily computed, with the results given in the next table.

Computation of original magmas of laccoliths.

	I.	II.	III.	IV.	V.	VI.
SiO_2	50.0	47.9	48.0	56.5	46.7	48.5
Al_2O_3	19.4	12.1	12.4	20.1	10.1	12.0
Fe_2O_3	3.9	3.5	3.5	1.3	3.5	3.0
FeO	2.7	4.8	4.7	4.4	8.2	7.4
MgO	2.2	8.6	8.3	0.6	9.7	7.8
CaO	5.0	9.4	9.2	2.1	13.2	11.1
Na_2O	3.6	3.0	3.0	5.6	1.8	2.5
K_2O	8.5	5.6	5.8	7.1	3.8	4.4

I. Syenite (borolanose) from Shonkin Sag laccolith.
II. Shonkinite (montanose) from Shonkin Sag laccolith.
III. Mixture, 1 part syenite and 19 parts shonkinite, of I and II.
IV. Syenite (pulaskose) from Square Butte.
V. Shonkinite (shonkinose) from Square Butte.
VI. Mixture, 13 parts syenite and 56 shonkinite, of IV and V.

When one considers that the relative volumes are approximations and that the composition of small pieces is held to represent the composition of large masses, it must be confessed that III and VI are very much alike; they represent the same magma and differ mostly in ferrous iron and lime—a result which is due to the fact that the specimen from which analysis V was made probably contains rather more augite than the average of the whole mass.

It is clear, then, that the laccoliths could have been formed by the intrusion of bodies of a shonkinitic magma from a source below, which furnished a uniform material, and that the syenite masses in that case must have been produced by the local interior concentration of a very small part of the feldspathic elements of these magmas.

So far as the writer can see, the arrangement of the varied parts in the laccoliths could have occurred only in one of three ways: First, there might have been by some process an injection of shonkinite, and afterward one of syenite into its center. Against this the mechanical difficulties seem insurmountable; there is no explanation of the lack of contact phenomena between the two kinds of rock; it is difficult to understand why the process occurred in two laccoliths while in the third there should be a gradual transition from shonkinite to syenite, and why separate upward movements of syenite magma should occur in this region only in the centers of the laccoliths. In view of these facts this theory may be confidently dismissed.

OSMOTIC THEORY.

The structure[a] of the laccoliths has been explained by the assumption that the magma was really of a syenite character, and that by

[a] Johnston-Lavis, H. J., Highwood Mountains of Montana and magmatic differentiation, a criticism: Brit. Assn. Adv. Sci., Rept. Liverpool Meeting, 1896, p. 792.

absorption of sedimentary material it became changed to shonkinite—lime, iron, and magnesia being the oxides absorbed. This is the osmotic theory. The writer has already pointed out[a] that this view is untenable for several reasons. There are no sediments in this region which have the proper composition to effect such a change, which must have taken place after the intrusion. There is nothing wanting in the sediments, and one can plainly see in the Shonkin Sag laccolith that the beds have simply been lifted and that nothing has been absorbed. Moreover, the intrusion has occurred in sandstones, not in calcareous, magnesian, iron-bearing beds. In addition, it is not a question of a narrow basic mantle, for, as just pointed out, the greater part of these masses consists of shonkinitic magma, and therefore, in the case of Square Butte, for example, the amount of material absorbed would have to be sufficient to reduce the 12.8 per cent alkalies of the syenitic rock to the 5.6 per cent of the shonkinitic, or to increase the magnesia from 0.6 to 9.7 for four-fifths of the entire mass. This would require the melting up and absorption of an incredible amount of country rock when one considers the amount of magma. Again, one may pertinently ask, If this occurred in the laccoliths why did it not occur at Highwood Peak, where the syenitic rock is found in direct contact with similar sediments without any basic border intervening? Whatever may be the merits of the osmotic theory in explaining the phenomena seen in other regions—and in regard to them the writer offers no opinion—it is certain that in the localities in Montana studied by him, at Castle Mountain, at Yogo Peak, and in the Highwoods, where basic outer rock mantles occur, the hypothesis has not a leg to stand upon, and it would never be offered by any petrographer who had studied the occurrences in these districts.

The facts disclosed compel us to fall back upon the third method of explanation—that the laccoliths have been formed in the place where they now are by processes which took place in a body of magma that was originally homogeneous.

THEORIES OF DIFFERENTIATION.

The term differentiation has been consistently used by the writer for a number of years to express the idea that different rocks are formed from a parent body of homogeneous magma without reference to the processes which have caused this result. This is considered to be demonstrated through the repeated observations of a great number of careful and competent students of petrologic phenomena. In the opinion of the author this term should be used in a geologic sense, as in a geologic way it has been demonstrated. Many theories have been advanced in explanation of this process along the lines of physical chemistry, but no one of them has been admitted by all to be a competent cause in every case. This in no

[a] Shonkin Sag laccolith: Am. Jour. Sci., 4th series, vol. 12, 1901, p. 13.

wise invalidates the actuality of the process. The geologist has pointed out the fact; it remains for the physical chemist to explain it if he can. Nothing is to be gained by denying it.

The many discussions of this subject which have been presented by workers in petrology are so well known that the writer has no intention of giving them in résumé in this place; the more important ones have been recently well summed up in a paper by Schweig[a] on the differentiation of igneous magmas, who adds an important suggestion of his own, which will be considered later. The theories may be classified into three groups—those which depend on the force of crystallization, those depending on some other form of molecular flow, and those which appeal to some force whose methods of operation are unknown, such as electricity.

Becker[b] has shown that pure molecular flow or diffusion is an agency acting with extreme slowness, and therefore as an explanation for such relatively small bodies of magma as the Highwood laccoliths intruded into the upper crust and cooling with relative rapidity, the writer is not inclined to regard it as competent or probable. Its rapidity, however, supposing that it can take place, must depend in large measure on the fluidity of the magma, and this is of necessity more or less unknown. It must not be forgotten, however, that so long as crystallization is able to take place the viscosity of a magma is never too great to prevent molecular flow, since it is through this that the molecules are able to arrange themselves in crystal form. The molecular oxides may not move over a great distance, but they are able to move.

Schweig[c] has offered the important suggestion that differentiation may be caused by the crystallizing out of definite minerals through fall of temperature or increase of pressure and the separation of such crystals from the mother liquor through specific gravity. If this takes place under high pressure, then by the removal of such pressure the crystals would become melted again and furnish chemically different magmas.

It seems rather difficult to accept this view in the simple form thus stated, as experience does not seem to show that there is the settling out of crystals through a greater specific gravity as postulated. Nothing is more common than to observe great vertical thicknesses of igneous rocks exposed by erosion, often for several thousand feet, and find that they are of uniform character throughout from top to bottom. This the author has seen repeatedly, and many instances will occur, no doubt, to all petrographers. Indeed, the author has never seen any instance where a direct proof of such settling could be observed, though a few are claimed in the literature. On the other

[a] Differentiation der Magmen: Neues Jahrb. für Min., Beil. Bd. 17, 1903, p. 516.
[b] Some queries on rock differentiation: Am. Jour. Sci., 4th series, vol. 3, 1897, p. 21.
[c] Loc. cit., p. 563.

hand, a priori it would seem to be a very natural result, and where it does not happen its failure must be attributed to the viscosity of the mother liquor in which the crystals are formed. Yet it is evident that the mother liquor can not be so viscous as to prevent molecular flow, otherwise crystallization could not take place. These are perplexing questions, and our knowledge of the physical properties of molten magmas is as yet far too incomplete to enable us to answer them with certainty.

It must be admitted, however, that the cross sections of the Highwood laccoliths furnish some evidence that specific gravity has been a factor in their formation, for the bottom portions are composed, as has been shown, of a relatively great thickness of heavy femic rock, upon which rests a much less thickness of lighter salic rock, and then in the Shonkin Sag laccolith, the only one whose upper part is still uneroded, is a very small thickness of the femic type again. It would be interesting to know in this connection whether the association of syenitic and shonkinoid intrusive rock masses, described by Merrill,[a] if seen in better exposures or more thoroughly studied, would show the femic rock below as well as above the salic type, and thus conform to the Highwood occurrences. More complete study and description would give a better idea of what seems to be a most interesting occurrence of differentiation in place.

DIFFERENTIATION PRODUCED BY CRYSTALLIZATION.

In recent years rock masses which show differentiation in place have received great attention from petrographers, and justly so, since they furnish the most precise indications yet obtained concerning the nature of the processes that have caused differentiation. Especially is this true of those processes which show different border zones, such as the Highwood laccoliths. The tendency at present appears to be to view them as caused by some process of crystallization, and in this connection Washington[b] has pointed out that we should expect that rock type which appears in the largest amount to be the one formed at the border. This is on the principle that in the case of a solvent and solute it is the solvent that crystallizes out first, an idea which, as applied to crystallization in molten magmas, we owe to Lagorio.[c] Washington further suggests that the differentiated border zones would be found in laccoliths of medium composition, monzonitic and foyaitic, while in extreme types, such as are granitic on the one hand and gabbroid on the other, with the solvent in very great excess the small amount of solute would be mechanically caught and crystallized with it or forced inward and solidified as a small core at the center of the mass.

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[a] Notes on some eruptive rocks from Montana: Proc. U. S. Nat. Mus., vol. 17, 1895, pp. 643, 665. Conf., also, Bull. U. S. Geol. Survey No. 110, 1893, p. 43.

[b] Igneous complex of Magnet Cove: Bull. Geol. Soc. America, vol. 11, 1900, p. 409.

[c] Tschermaks Min. Mitt., vol. 8, 1887, p. 513.

This conception of Washington's with respect to the femic ("gabbroid") type is perfectly realized in the Shonkin Sag laccolith.

Washington, however, attributes the whole process to the force of crystallization, and does not deem convection currents to be at all essential.[a] He says: "It would go on by collecting along the rough borders in accordance with the well-known tendency of crystallizing bodies to grow about sharp nuclei, the solute molecules being mechanically pushed aside toward the center."

With this view, which is a clear exposition of the idea, also expressed by others, that the force of crystallization is alone competent to produce differentiated border zones, the writer can not agree, because, as it seems to him, there is a misconception involved in it, for a series of very small units is made to do duty as one very large unit. Let us suppose that we have a mass of mobile magma a mile in diameter and that the moment has arrived in the process of cooling when some compound can crystallize out. This begins at the outer border, as stated, and not at the center. Now, in the center are oxide molecules, which are to be moved to the outer border, a distance of half a mile. It can scarcely be thought that the force of crystallization can act through an intervening distance of such magnitude with a pull sufficient to attract the central molecules to the outer border, for crystallization acts only through relatively short distances. It is of no aid to the solution of the problem to think that at any intervening distance the molecules would come together and form another crystal, for the moment that has happened the forces of crystallization would, so to speak, come to rest and cease to operate. The crystal, then, at the intervening distance is, so far as the forces within its radius of action are concerned, a dead body, and we must find some force other than that of crystallization to transport it to the outer border. Unless the pull is felt from border to center it is difficult to see how crystallization can operate. It might also be imagined that the force does not operate directly upon the central molecule, but indirectly through the intervening ones, these being linked together, by their tendency to crystallize, like a train of cars. The train as a whole would then move in the direction of the molecules at either end, upon which a stronger force operates, and in this case the locomotive that moves it are those molecules at its outer end, which, being within the crystallizing influence of the outer border, are irresistibly drawn forward to the solidifying crystal. Then come the next in the train, and so on.

The objection to this method of explanation is that, if the attraction between the mineral molecules were strong enough to act as a link in the train, they would crystallize and the continuity of the train would be broken. We should have to imagine the whole mass in a state of absolute equilibrium, each molecule attracted equally in all directions by

[a] Loc. cit., p. 410.

its fellows, the whole being drawn without a break in the continuity of events toward the outer border. Should there be a break anywhere in the equilibrium, the molecules would fly together and crystallize in that spot, which would set up a new center of attraction as powerful as any spot at the outer edge, and the molecules would, over large areas, move thither, and this of course would disturb the equilibrium elsewhere; thus the whole mass would go on crystallizing without reference to the outer border. In fact, if we appeal to crystallization alone in this way, convection currents are not only no aid but they can not be present, since they would tend to disturb equilibrium, and there must be no disturbance of any kind. Thus it appears to the writer that the mere statement of the conditions necessary for this view are sufficient to refute it. It seems that if we consider crystallization alone as the operating force, in the ultimate analysis it resolves itself into the force acting from border to center, and when one considers the magnitude of the distance and the frictional resistance in the magma, which in any case can never be perfectly mobile, but must possess a certain amount of viscosity, it does not appear possible to appeal to this alone as a competent agent to produce such results. Accepting crystallization alone, it would also be difficult to explain why the lower layer of femic rock is so very thick and the upper one so very thin.

ELECTRICITY.

Some writers have suggested that electric currents may play some function in the process of differentiation. But as yet we know so little in regard to the electric properties of molten magmas, beyond the fact that they appear to be similar to aqueous salt solutions,[a] that nothing of value can be advanced in this direction. When electricity is suggested as a possible agent the thought of the German proverb comes irresistibly to mind:

> "Was man sich nicht erklären kann
> Das sieht man als elektrisch an."

COMBINED EFFECT OF CONVECTION AND CRYSTALLIZATION.

In the original paper on Square Butte the writer placed great stress on molecular diffusion, and was inclined to believe that crystallization had played no part in determining its differentiation, the fact that different femic minerals were found in the two rock varieties leading to this conclusion. In the light of recent work, and especially of Becker's proof of the slowness of molecular diffusion, this view should now be modified, and it is thought that a combination of convection currents and the tendency to crystallize first at the outer walls of the laccolithic chamber may possibly be sufficient causes. It seems

[a] Barus and Iddings, Electrical conductivity in rock magmas: Am. Jour. Sci., 3d series, vol. 44, 1892, p. 242.

almost impossible to resist the view that in an inclosed mass of magma sufficiently mobile for local differentiation to take place convection currents due to unequal cooling would occur. On the upper surface and along the outer walls cooling would take place more rapidly; on the floor of the chamber, protected by the heated mass above and with heated rocks below, less rapidly. Thus there would be a tendency along the top and sides for the magma to grow heavier and to descend. Material from the more highly heated central part would tend to rise and replace this, and thus currents would be established in the magma, rising in the center, flowing off to the sides at the top, and descending along the cooler walls. This process is illustrated by the familiar experiment of showing the convection currents in a vessel of boiling water with sawdust. Such currents, once established, would continue as long as sufficient mobility remained in the magma to permit them.

At some period crystallization would take place, and this most naturally would begin at the outer walls. It would not begin at the top because the material would arrive there from below at its highest temperature. Moving off toward the sides the material begins to cool and descend and becomes coolest as it nears the floor; here crystallization would commence. The first substance to crystallize is the solvent, which in this case would be the femic minerals, chiefly augite. Part of the material solidified would remain attached to the outer wall and form a gradually increasing crust, and part would be in the form of free crystals swimming in the liquid and carried on in the current. Probably at first, as the liquid moved inward over the floor of the laccolith and became reheated, these crystals would remelt, giving rise to numerous small spots of magma of a different composition, which would slowly diffuse. As time went on, however, there would be a constantly increasing tendency for the crystals to endure; they would be carried greater and greater distances. But as they are solid objects and of greater specific gravity than the liquid, there might be a tendency for the crystals to drag behind and accumulate on the floor of the chamber. Moreover, from the heat set free at the time of their crystallization and from the resulting concentration of the chemically combined water vapor in the magma, the residual liquid would tend to have its mobility kept undiminished, since these would be factors which would tend to counteract the increase in viscosity due to cooling. In this manner it may be possible to understand how there would form a femic marginal crust and a great thickness of the femic material at the bottom of the laccolith. As the cooling went on the edges of the outer crust would rise more and more toward the top, finally spreading over it, and as a result the crust should be thinner on the top than elsewhere, as in the Shonkin Sag laccolith, in which the upper crust of femic rock is still preserved.

If, notwithstanding the evidence previously mentioned, there is a tendency for the crystals, on account of their greater specific gravity, to overcome viscous resistance and sink through the fluid, this might greatly aid in the process just described. And it is also possible to imagine that if the crystals melted there might be, in spite of diffusive tendencies, a retardation in some degree of the spots of more femic magma thus formed and their local accumulation.

In this way the solute—in this case the oxides which form feldspars—might gradually accumulate toward the center and eventually solidify there. The process might go on until a definite eutetic solution resulted, when crystallization might produce a rock very different from that which had been forming. This would explain the case of the salic rock of Square Butte, for the resulting inner mass contained such a proportion of the femic elements, water, vapor, etc., that these combined to form hornblende instead of augite. In the Shonkin Sag laccolith the water vapors appear to have largely concentrated along the inner walls of the outer femic crust, producing, when the inner mass solidified, a mantle with pegmatitic development. Although the erosive dissection at Palisade Butte is much greater than at the other two laccoliths, the remaining portions would seem to indicate that the process went on much more rapidly, and consequently the separation into parts was much less pronounced. The explanation just offered is based, with modifications, essentially on the suggestion of Becker[a] as to the process by which differentiation can occur in laccoliths through a combination of crystallization and convection currents.

The hypothesis tentatively offered above seems to explain those, the most common, cases of laccolithic differentiation in which the outer shell is of femic type; it does not so well explain those with a salic outer shell. Washington[b] has suggested that in those magmas of preponderant salic character the salic molecules compose the solvent, and as this crystallizes first it produces the salic mantle. The only difficulty in this view is that it would then be necessary to show that in the rock mass composing the salic mantle the salic minerals have crystallized first, and are therefore automorphic against the femic ones, thus proving that the latter crystallized last. The writer does not know of any evidence concerning this point in the literature, and has never had the opportunity of studying a distinct laccolith with salic border, the only case where the mass was more salic at the margin, coming under his observation, being the Blackhawk intrusive stock in the Castle Mountains.[c] In this case the mass was not an inclosed body of magma such as would be formed in a laccolith, and

[a] Fractional crystallization of rocks: Am. Jour. Sci., 4th series, vol. 4, 1897, p. 257.

[b] Loc. cit., p. 410.

[c] Weed and Pirsson, Geology of the Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896, p. 89.

it passes from a granular rock at the center to a porphyry at the outer edge, and the process appears to have been otherwise than in the Highwood laccoliths.

DIFFERENTIATION IN THE STOCKS.

The process of differentiation suggested above for the laccoliths could not apply to the stocks which form eruptive centers, at least not without modification of the process. This is perhaps the best illustrated at Highwood Peak. Here we find the same association of salic and femic types seen in the laccoliths, but while the two taken together form a single mass intruded in the sediments, there is no such orderly arrangement of parts, and the two kinds have a sharp contact against each other, the pulaskose being the later, since it holds angular fragments of the monzonoid rock. There have been, therefore, two successive upthrusts of magma, the second after the former had solidified; and the differentiation has not occurred in the place where the masses now are, but at some lower level; and it also could not have been by the separation of a solid from a liquid by the simple process suggested above in the laccoliths, since both were intruded in liquid form.

The suggestion that a differentiated stock might be explained by laccolithic differentiation below, followed by a later upward movement of the mass, has been already made by the writer in the case of Yogo Peak, in the Little Belt Mountains of Montana,[a] and this idea has been recently extended by Prof. F. D. Adams to explain the varied rock types and their arrangement at Mount Johnson, in the Province of Quebec,[b] where syenite (laurvikose) is found associated with essexite (essexose). In this case, however, the rock varieties grade into each other; there is not a sharp contact between them, showing that the upward movement took place before any solidification occurred and involved both alike. This might have been the case at Yogo Peak, but could not have been at Highwood Peak, as mentioned above.

From this center of eruption there have been in all four upthrusts of magma, two of them shown by extrusive flows, two in the stock itself. They have occurred in the order and with the compositions shown in the subjoined table:

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[a] Petrography of the igneous rocks of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 566.

[b] The Monteregian Hills: Jour. Geol., vol. 11, 1903, p. 281.

Composition of Highwood Peak magmas.

	I.	II.	III.	IV.
SiO_2	59.2	48.0	51.0	65.5
Al_2O_3	13.8	13.3	17.2	17.8
Fe_2O_3	5.5	4.1	2.4	.7
FeO	1.4	4.2	4.2	1.1
MgO	4.5	7.0	6.2	1.0
CaO	5.6	9.3	9.1	.9
Na_2O	3.1	3.5	2.9	5.5
K_2O	4.2	5.6	4.9	5.6

I. Adamellose (trachyandesite) flow from North Willow Creek.
II. Shonkinose (analcite-basalt) from Pinewood saddle.
III. Shoshonose (monzonite) from Highwood Peak.
IV. Pulaskose (syenite) from Highwood Peak.

This is based on the view that the stocks are of later age than the extrusives surrounding them. At East Peak, for example, this is clearly the case, for the two, as described elsewhere, are seen in contact, the stock cutting upward through the effusives. They are not seen in such clear contact at Highwood Peak, and yet the arrangement, as may be seen on the map, is such as to lead to this conclusion, which is, moreover, the general one in such cases.

Repeated attempts have been made to discover whether in the above series of analyses any mathematical relations are present which would throw light on the processes of differentiation or would serve to connect them with the other magmas of the area. These attempts have not been so completely successful as could be wished. The great difficulty in the way of such work is that we have no exact knowledge of the relative volumes of magmas involved. Some general facts are, however, clear. Thus, if we should suppose that II has differentiated out of I, we can see that there is much less silica, the same alumina, a large increase in ferrous iron, lime, and magnesia, and a small increase in alkalies, especially potash. If it were true that II represents a differentiated product of I, then there should be a complementary magma to correspond. Using various proportions of I and II, attempts have been made to calculate this magma and see if it would be shown by III, IV, or some other analyzed magma of the district, but without much definite success. The study that has been made leads to the conclusion that all four represent differentiated products, and if they have developed from a parent magma then m I+n II=a and m III+n IV=b, while m'a+n'b= original magma, and none of these have been found and analyzed. We do not know the relative volumes, as we did in the laccoliths, and can not therefore assign values

to m, n, m', and n' and discover the exact composition of the original magma or of its first cleavage products.

It is of interest to note, however, that if we assume the simplest case, that the volumes of all four are equal—that is, if we take their simple averages, we obtain these results:

Averages and comparison of analyses.

	A.	B.	C.	D.	E.
SiO_2	53.6	58.2	55.9	52.9	52.1
Al_2O_3	13.5	17.5	15.0	15.6	15.0
Fe_2O_3	4.8	1.6	3.2	3.0	2.7
FeO	2.8	2.6	2.7	4.8	5.5
MgO	5.8	3.6	4.7	5.2	5.4
CaO	7.4	5.0	6.2	8.2	8.1
Na_2O	3.3	4.2	3.7	3.2	3.1
K_2O	4.9	5.3	5.1	4.9	6.1

A. Average of I and II from Highwood Peak center.
B. Average of III and IV from Highwood Peak center.
C. Average of I, II, III, and IV from Highwood Peak center.
D. Average of monzonite analyses (Petrography Little Belt Mountains, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 478).
E. Borolanose (basic syenite) from Middle Peak stock Highwood Mountains.

The examination of the average of these analyses will show that it is that of a typical monzonitic magma. In D there is given for comparison the average of a number of analyses of monzonites used in the description of the rocks of Yogo Peak. It has a very close resemblance to this. It is also of interest to observe that, while neither it nor I nor II is exactly like any Highwood magma, they have a general resemblance to many of them; for example, C and E are much alike. In this connection it should be recalled that the Middle Peak stock is much older, as shown elsewhere, than any of the products of igneous activity belonging to the Highwood Peak center, and that, with the exception of possessing a border facies, which differs from the main mass chiefly in a textural manner and either not at all or but very slightly in a chemical way, it is entirely undifferentiated. It is therefore probable that it represents the original magma from which I, II, III, and IV have differentiated, and it is possible that by combining them in the proper proportions this composition could be more exactly realized. The other stocks of the area are of the same category as that at Middle Peak, and the further discussion of the origin of all these is deferred until that of the dikes has been taken up.

COMPOSITION OF THE ORIGINAL MAGMA.

Before dismissing the stock rocks it is of interest to surmise yet further what might have been the composition of the original magma from which they were all derived. It is understood that this can, of course, only be done by averaging those of them of which we have analyses. For this purpose there are available analyses of the Middle Peak, East Peak, and Arnoux stocks. To use the Highwood stock, we must obtain some average of its two rock types. The monzonitic rock is, however, in excess over the syenitic, how much is not known, but certainly more than twice as much is present. To be on the safe side, we will assume it is twice as much, not more. If this is added and the average of all four taken, we shall have the result given in column A of the following table. In column B is given the analysis of the Middle Peak stock, which, as previously mentioned, is much the oldest in the district, and therefore probably the least differentiated. Considering how rough such an approximation must be the agreement is really very close. It seems probable, then, that the original magma from which all these rocks were derived had approximately the composition shown in column A.

Average and comparison of analyses.

	A.	B.
SiO_2	52.2	52.0
Al_2O_3	15.3	15.0
Fe_2O_3	3.3	2.7
FeO	4.4	5.5
MgO	5.2	5.4
CaO	7.8	8.1
Na_2O	3.3	3.2
K_2O	6.1	6.1

DIFFERENTIATION AND DERIVATION OF DIKES.

Just as in the preceding section it has been shown that a lack of definite knowledge of the relative volumes of the magmas prevents us from obtaining exact results by combining them, so the same difficulty arises in trying to determine the origin and derivation of the dikes. In spite of this, however, some general relations may be shown which are interesting and instructive. For instance, the dikes in and around Highwood Gap are clearly referable to either salic or femic types, and taken together they are complementary, so that it seems probable that if combined in proper proportions they would indicate the parent magma from which they were derived. For this purpose there are four analyses, two of salic and two of femic types, as shown

by I, II, III, and IV in the subjoined table of analyses. In the next four columns, V, VI, VII, and VIII, are shown the averages obtained by combining each salic and femic magma in equal proportions.

Combination and comparison of analyses of dikes and stocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
SiO_2	58.0	57.2	46.0	47.8	52.0	51.1	52.9	52.5	52.0	51.8	52.2
Al_2O_3	17.3	18.5	12.2	13.6	14.7	15.3	15.4	15.5	15.0	14.5	15.3
Fe_2O_3	2.5	3.6	3.9	4.7	3.2	3.7	3.6	4.2	2.7	5.1	3.3
FeO	1.2	1.2	4.6	4.5	2.9	2.9	2.9	2.9	5.5	3.6	4.4
MgO	1.8	0.7	10.4	7.5	6.1	5.5	4.7	4.1	5.4	4.6	5.2
CaO	3.5	2.3	9.0	8.9	6.3	5.6	6.2	5.6	8.1	7.0	7.8
Na_2O	3.4	4.5	2.4	4.4	2.9	3.4	3.9	4.5	3.2	2.9	3.3
K_2O	10.1	8.6	5.8	3.2	7.9	7.2	6.7	5.9	6.1	7.6	6.1

I. Highwoodose (tinguaite-porphyry) from dike at Highwood Gap.
II. Pulaskose (tinguaite-porphyry) from dike at Middle Peak, South Peak ridge.
III. Cascadose (Highwood minette) from dike at Arrow Peak.
IV. Monchiquose (analcite-basalt) from dike at Highwood Gap.
V. Average of I and III.
VI. Average of II and III.
VII. Average of I and IV.
VIII. Average of II and IV.
IX. Borolanose (basic syenite) from dike at Middle Peak stock.
X. Fergusose (fergusite) from dike at Arnoux stock, Shonkin Creek.
XI. Average of four stocks.

In IX and X are analyses of two of the stocks and in IX the average of four of them, which has been obtained as explained on a previous page. The close general similarity of the averages obtained by this simplest of all methods among themselves and with the stocks and their average must convince every unprejudiced reader that it has been perfectly possible for the varied dikes to originate by the splitting up of the magmas represented in the stocks. It is also evident that it has been done in the main by the concentration of lime, iron, and magnesia in one portion of the original magma and a consequent enrichment in silica, alumina, and alkalies in another. The main differences between the stocks and the dike averages are in the relations of lime and ferrous and ferric irons. If we consider only total iron, disregarding the state of oxidation, the differences mostly disappear. In lime, however, the differences are over 1 per cent, but this is the only striking disagreement to be observed.

It will be noted that this presupposes that the volume of material of which the salic dikes are composed is equal in amount to that of which the femic dikes are formed, and it was pointed out at the beginning of this chapter that in actual volume as they appear at

the surface the salic dikes are very greatly outclassed by the femic ones. If we accept the view that the complementary dikes have been formed by the dissociative differentiation of a magma in composition similar to that of the Middle Peak stock, the unavoidable inference would be that the femic by-product had appeared at higher horizons in dike form much more largely than the salic, and that the greater part of the latter had solidified at lower levels as intrusive masses, to be, perhaps, exposed by later and deeper erosion. If this is so, it would be only in keeping with what the writer has previously pointed out as the rule in such cases.[a]

On the other hand, the salic dikes could have formed from a much more femic magma than that indicated above, just as the salic cores of the laccoliths have, though not necessarily by exactly the same processes, and this would, of course, have left much larger volumes of femic material to form dikes. Either this supposition or the one mentioned above is a perfectly reasonable one, and the evidence at hand is not sufficient to decide definitely between them.

GENERAL DIFFERENTIATION OF IGNEOUS ROCKS.

In a relatively small body of inclosed magma, such as we find in the laccoliths, it is not difficult to imagine a process by which differentiation has taken place and an outer femic mantle produced by crystallization aided by other agencies, such as convection currents. This involves the separation of a solid from a liquid, and evidently the differentiation in stocks, such as Highwood Peak and the complementary dikes where both varieties have been injected in liquid form, could not be explained in this way, at least not without modification. Still less could we explain thus the variation of the mass of one stock from the mass of another if we believe that they have been formed from some greater, deeper body of magma that was once homogeneous.

Schweig has suggested, as previously mentioned, that under sufficient pressure compounds might be forced to crystallize out, and that then, descending, through greater specific gravity, heterogeneity would be produced. If the pressure should then be relieved, they would be incapable of existing in solid form, would melt, and liquid masses of differing composition might thus be formed. In some ways this is a very tempting hypothesis. For instance, as has been shown, there occurred at Highwood Peak an eruption of salic lava (adamellose, trachyandesite) filled with more or less resorbed hornblende, and this was followed by femic lava (shonkinose, analcite-leucite-basalt) in which augite completely replaces hornblende. We could imagine that in the lava column under great pressure hornblende was forced to crystallize, especially as under such a condition the water vapor necessary for its formation, but not for augite, would be present.

[a] Am. Jour. Sci., vol. 50, 1895, p. 116.

These hornblendes, descending, through gravity, would enrich the lower portion of the column in lime, iron, and magnesia. When eruption then took place a salic lava would be ejected, and the pressure being removed the remaining hornblendes which had not yet had time to descend would start to remelt, but would not have time enough before the mass chilled and prevented complete refusion. Hence we find them partially resorbed. This would be followed by a femic magma, but the water having mostly escaped and the pressure been relieved with the establishment of the opening of the conduit to the surface, this lava would have iron ore, olivine, and augite in the place of hornblende, which had had opportunity to completely remelt.

So far the hypothesis is tenable, but in the following events we are confronted by the fact that at Highwood Peak, in the next eruption, that of the monzonitic rock of the stock, there is a less femic magma, which was succeeded by one the most salic in the whole district—a quartz-bearing pulaskose. Evidently some entirely new arrangement in the mechanism of movement and eruption must be devised to meet this. The same difficulty arises in the case of some of the dikes, whose order of succession is given in a later paragraph.

And again, if we accept what appears to be the field evidence at Middle Peak, the differentiated dikes made their appearance earlier than the stock whose composition they unitedly represent.

These will serve as fair examples, which might be almost indefinitely increased from other districts, of the difficulties that stand in the way of a complete acceptance of this theory. To them should be added, as already pointed out, the homogeneous character of masses exposed by erosion through great vertical distances. In fairness, however, it should be admitted that these difficulties are just as pertinent to many other explanations which have been offered for the differentiation of molten magmas as they are for this one.

As time goes on it becomes more evident that the problem is an increasingly complex one; no single explanation of one occurrence will do for all. In what we call the differentiation of rock magmas many factors have worked together; in one place one factor or set of factors has been dominant, in other places these are less so. For a single occurrence a satisfactory explanation may be offered, but a general one must take a comprehensive view of the whole field, of the varied phenomena to be explained, and of the difficulties which arise. There are varied agencies to be considered—crystallization, convection currents, molecular diffusion under varied aspects, tendency to form eutectic mixtures, addition and subtraction of water vapor, increase and decrease of heat, increase and relief of pressure, the mechanism of the movements of magma produced by crustal displacements, the effects of these upon the relative saturation of the magmas with certain compounds, the effects of varied electrical status, and many others.

The truth of the matter is that we are as yet not at all prepared to give a general explanation of the differentiation of magmas. There are many things to be learned before we can do so. Every suggestion which has as much merit as that of Schweig's helps, but can not be accepted for the whole truth. It appears to the writer that at the present time a statement of the problem presented by some of the phenomena and of the difficulties to be met would be most useful and would perhaps tend to prevent the development of obviously wrong hypotheses. Further discussion of this subject here would transcend the proper limits of this work, and the writer hopes to take it up at another time and place.

MATHEMATICAL RELATIONS OF MAGMAS SHOWN BY GRAPHIC METHODS.

In the discussion of the origin of the rocks of the Little Belt Mountains the author showed[a] that their molecular ratios, as given by the analyses, could be arranged in a simple linear series forming a diagram from which, if the percentage of one oxide of an element in a rock in the district was known, its entire chemical composition could be deduced. Washington[b] has extended the same process to the complex at Magnet Cove, Arkansas. With the Highwood analyses the attempt to form a similar simple linear series has not succeeded, and it is evident that they are more complex or that the requisite data are not at hand. In addition to the relations which have been previously given in this discussion others might be shown; thus, if we should take one part of the syenitic rock of the Square Butte laccolith and combine it with one part of the shonkinoid portion of the same mass (see III and XVII of the table of Highwood analyses previously given), we should obtain the result presented in column A below, which may be compared with the analysis of the Middle Peak stock, given in column B. The general resemblance is very close.

Comparison of analyses.

	A.	B.
SiO_2	51.5	52.0
Al_2O_3	15.0	15.0
Fe_2O_3	2.4	2.6
FeO	6.3	5.5
MgO	5.1	5.4
CaO	7.6	8.1
Na_2O	3.7	3.2
K_2O	5.4	6.1

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 569.
[b] Foyaite-ijolite series of Magnet Cove: Jour. Geol., vol. 9, 1901, p. 645.

Although such relations are to be seen, the attempt to combine them and to place the whole group in mathematical relation has so far not succeeded, possibly because there is no definite relation, but in the belief of the writer it is because there is in this series no such initial starting point as was afforded by the analyses of the differentiated mass of Yogo Peak.

ARRANGEMENT OF VOLCANIC CENTERS.

There is no particular plan in the arrangement of the volcanic centers in the Highwoods; they show no such disposition as would enable one to say that they are placed on fault lines. It is evident that there is no profound faulting or tectonic disturbance to be seen in the Highwood area; the facts at hand are quite to the contrary. The general plan of the mountains and their geologic history already given show that the first upward movements of the magmas began with intrusion of laccoliths and of one stock. There is no evidence that this was attended by surface outbreaks, though this may have been the case. These movements were attended with shattering of the strata and the intrusion of dikes, and it was through this mass of weakened strata that the later outbursts took place, with intrusions of stocks now here now there. The outbreaks at the Shonkin center were of great violence and attended with profound effects upon the circumjacent beds, as is clearly shown by the remarkable aureole of radiant dikes that surround it, though it is possible that these were initiated near the stock in part by the contraction due to later loss of heat. The volcanic centers then appear to be caused by local outbreaks, the reason for the original selection of this locality not being evident.

There is at the present time with some geologists a tendency to deny that volcanic centers of eruption are determined by fault lines and fissures. It is true that in many regions they do not show any direct evidence of this, and the facts appear to indicate that they may occur quite independent of such lines, but it seems to the writer that it is not necessary to suppose they have been formed only after one method. The great amount of direct evidence at hand proves that they are sometimes located upon fault lines and sometimes they have been started by explosive chimneys blown through the crust, such as the Maaren of the Eifel district. In this case they do not have a definite arrangement of ground plan.

The Castle Mountain volcano to the south seems an example in this part of Montana of the relation between volcanoes and fault lines.[a]

[a] Weed and Pirsson, Geology of the Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896.

AGE AND ORDER OF SUCCESSION OF THE IGNEOUS ROCKS.

The absolute geologic age of the period of volcanic activity in the Highwood group can not be any more nearly told than that the products break through or are piled upon the Montana formation of the Cretaceous system, which are the youngest stratified rocks of the region. The outbreaks, however, may date from a somewhat later period than the close of the Montana, for the eastern laccoliths, which are probably the oldest igneous rocks, lie in the Montana itself, and the form and granular character of the masses indicate that these intrusions took place at considerable depths below the surface. There may then have been upon them beds younger than the Montana, which have since been carried away by erosion, but there is no direct evidence of this. It is evident, from the fact that the fragmental volcanic material lies in places practically upon the same beds as those which form the floor of the laccoliths, that a long period of erosion must have separated the intrusion of the latter from the outpouring of the former. How long this period was we have no means of judging, but one thing is certain, that the general geologic relations of the district and the character of its rocks indicate that its igneous activities are to be referred to a single geologic time phase. It is to be noted also that no beds of later age than the Montana are to be seen under the edges of the eroded cover of volcanic débris. From all of these circumstances it may be inferred that the time of igneous activity in the Highwoods was coincident with that of the general geologic disturbances at the close of the Cretaceous and in the early Tertiary, which have so profoundly affected the general Rocky Mountain region.

The order of succession of the igneous rocks has, in part, been previously mentioned. The geologic facts at our command show clearly distinct periods in the order of succession of the upward movement of the molten magmas, as follows: First, intrusion of the laccoliths, followed by very considerable erosion; second, outbreaks of volcanic activity yielding feldspathic lavas, followed by some erosion; third, intrusion of the stocks into the masses of feldspathic and basaltic extrusives.

Connected with these main episodes are a number of minor ones which deserve consideration on account of their bearing on the petrologic history of the region. The stock at Middle Peak, on the ridge between Highwood and South peaks, must be much older than the other stocks and antedate the outbreaks of extrusive material. This seems clear from the position of the sedimentary beds in the ridge, which are horizontal and in undisturbed position right up to the contact of the intrusion. It is impossible to imagine that the intrusion could have occurred along the crest of a narrow ridge composed of horizontal beds, displacing one half of the ridge and yet not disturb-

ing the short, narrow strips of strata left in the other half. A great amount of erosion has occurred, by which the stock has been exposed to depths yielding moderately coarse granular rock and the surrounding strata carried away, the most resistant portion, the contact edge of metamorphosed sediments, standing up as a ridge. Far below this ridge, down in the valleys, as at Comb Butte as well as upon it, lie extrusive materials, and into these extrusives the other stocks are thrust. Hence the intrusion of Middle Peak, like that of the laccoliths, antedates by a considerable period of erosion the volcanic outbreaks, as stated above.

The ridge, however, as shown on the map, is cut transversely by a great number of dikes, of both feldspathic and basaltic types. These have also aided in the metamorphism and general stiffening of the structure and in resistance to erosion. They run directly to the contact edge of the stock and then cease. For this reason they clearly appear to be cut off by it and to be older than it is. While the exposures of the stock on the western slopes of the ridge are much broken down and largely of slide rock, this general fact seems evident. The evidence in the field then shows that there was here, first, an intrusion of various dikes, then that of the stock cutting them off, then a period of erosion, and then volcanic outbreaks. The field evidence in regard to the dikes is, on the other hand, opposed by a certain petrographic fact—exactly the same types of rocks found in the dikes are also found elsewhere in the area in other dikes cutting the breccias and therefore of much later date. This is especially notable, for example, in those basaltic types full of large biotite phenocrysts (Highwood minettes), called in the new classification "phyro-biotitic shonkinose." One of these occurs on the Middle Peak ridge and also cutting the extrusives of Lava Peak. It is, of course, in nowise impossible that this should occur, yet at the same time it is surprising to find such a peculiar and distinctive type of rock produced at two different periods separated by a long interval of time. The field evidence, however, is so much the stronger that we must accept this as a fact, if the previous interpretation is correct. That it is is also indicated by the recurrence of certain peculiar leucitic types in the laccoliths and again later in and around the Shonkin core.

In regard to the relative age of the feldspathic and basaltic dikes in the Middle Peak ridge, the only evidence was found on the slopes leading down to Highwood Gap, where the basaltic type was found in one case clearly cutting the feldspathic.

In regard to the later system of dikes, all that can be said is that the basaltic ones cut the basaltic flows and breccias and that the feldspathic ones cutting the Shonkin stock are, so far as we have evidence, the latest rocks of the region.

Summing up, then, all the evidence at hand as previously given, we have as the full order of succession of the igneous rocks:

1 { Intrusions of laccoliths (salfemic magmas splitting into dosalic and salfemic).
a Intrusion of dikes, feldspathic (dosalic).
b Intrusion of dikes, basaltic (salfemic).
c Intrusion of Middle Peak stock (dosalic).

2 Erosion interval, followed by Highwood volcano.

3 { *a* Outbreak of feldspathic (dosalic) lavas.
b Outbreak of basaltic (salfemic) lavas.
c Intrusion of Highwood monzonite (dosalic).
d Intrusion of Highwood syenite (persalic).

4 Short erosion interval, followed by Shonkin volcano.

5 { *a* Outbreak of basaltic (salfemic) lavas.
b Intrusion of stocks, Shonkin, East, and Arnoux (salfemic).
c Intrusion of dikes, basaltic (salfemic).
d Intrusion of dikes, feldspathic (dosalic and persalic?).

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 237.]

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